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PLATES 5—9

No. 4—THE ORDOVICIAN ROCKS BETWEEN COLLON (CO. LOUTH) AND GRANGEGEETH (CO. MEATH)

By JOHN C. HARPER

No. 5—THE ORDOVICIAN VOLCANIC ROCKS BETWEEN COLLON (CO. LOUTH) AND GRANGEGEETH (CO. MEATH)

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No. 4

THE ORDOVICIAN ROCKS BETWEEN COLLON (CO. LOUTH) AND GRANGEGEETH (CO. MEATH)*

BY

JOHN C. HARPER

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(Communicated by the late Professor L. B. Smyth).

Plates 5, 6 and 7

SUMMARY.

The paper describes the northern part of the inlier of Ordovician rocks which lies between the towns of Collon, Co. Louth, and Navan and Slane in Co. Meath. A volcanic series, consisting of tuffs, lavas, and autobreccia, contains in its upper part a fauna of Caradoc age which shows affinities with the Balclatchie fauna of Girvan, and also relations to the Kuckers fauna of Esthonia. Overlying these beds are black shales containing graptolites of *Dicranograptus clingani—Pleurograptus linearis* age. Associated with the black shales are thin bands of tuff and some mudstones which have a fauna of cyclopygids and agnostids suggestive of the Whitehouse beds. Some members of the brachiopod and trilobite fauna are described and illustrated including three new brachiopod species.

INTRODUCTION.

The area dealt with is situated about 8 miles west of Drogheda, and lies near the south-eastern apex of the roughly triangular mass of Lower Palæozoic rocks lying between Bangor, Co. Down, in the northeast, Longford in the southwest, and Slane and Drogheda in the southeast. The northern part of this mass represents the Irish continuation of the Southern Uplands, the Ordovician rocks along its northern boundary corresponding to similar rocks in the Northern Belt in Scotland ; further south, Silurian greywackes and mudstones with small inliers of black graptolitic Ordovician shales correspond to the Scottish Central Belt. Southeast of a line from Dundalk to Virginia the beds are all shown as Silurian on the 1 : 1,000,000 map of Ireland (1928), except for a small inlier of Ordovician shown just south of Ardee, Co. Louth. There is, in fact, a considerable area of Ordovician, and the rocks inside

*The author is indebted to Mr. B. E. Manistre for petrological determinations which have been of great help in the preparation of the map Pl. 7. The igneous rocks are described by him in the succeeding paper.

the triangle bounded by Collon, Navan, and Slane are almost entirely of this age, consisting of lavas, tuffs, and black graptolitic shales. This Ordovician has no counterpart in the Southern Uplands, and the regional strikes suggest that it would correspond to a position between the Lake District and the Southern Uplands in Britain, so that the shelly faunas which have been obtained in the area are of some interest.

This Ordovician is bounded on the west by a fault which runs from near Collon southwestwards to the neighbourhood of Navan, bringing down the Silurian. On the south the River Boyne, from Navan eastwards to Slane, roughly marks the boundary of the overlying unconformable Carboniferous Limestone ; on the east Silurian rocks appear again but the boundary is obscured by drift. A narrow wedge of Silurian crosses the Ordovician in a north-east—south-west direction just to the south of Grangegeeth, and the rocks dealt with in this paper are those to the north of this wedge. The area lies on Sheets 81 and 91 of the one-inch Geological Survey Maps of Ireland, the former of which had two editions (1870 and 1901), and the latter three editions (1867, 1870 and 1901) ; the two maps are described in the corresponding memoirs (Hull, Leonard, and Baily, 1871, and Hull, Cruise, and Baily, 1871). An inspection of these maps will show that there was considerable uncertainty as to the age of the beds and the rock types, the latest edition of sheet 91 by no means being the most correct.

The Stratigraphical Succession.

The exposed Ordovician rocks are predominantly volcanic and unfossiliferous, but some of the tuffs contain a shelly fauna, and there are also black graptolitic shales. The succession is not easy to piece together with certainty owing to the thick cover of boulder clay over a large part of the area and to the considerable lateral variation in the tuffs and sediments. The following is considered to represent the sequence :—

3. Oriel Brook Mudstones with Upper Whitehouse Fauna.

2. Black graptolitic shales of Broomfield and Oriel Brook (zones of *Dicranograptus clingani* and *Pleurograptus linearis*).

1. Grangegeeth Volcanic Series.

d. Upper Tuffs and Shales (including the brown shales of Mellifont) with Balclatchie fauna.

c. Brecciated Keratophyres.

b. Basaltic Group.

a. Lower Tuffs and Intercalated Lavas.

The Lower Tuffs and Intercalated Lavas. The lowest exposed beds are hard greenish keratophyric tuffs, usually without any obvious bedding, which are succeeded by well-stratified brown-weathering tuffs seen in two quarries, localities 26 and 40*, along the Glassallen road from Newtownfortescue (locally known as Newtown and so named on the map, Pl. 7). These tuffs consist of alternating finer and coarser bands, and are often flaggy. They are muddy in places, but have

*Locality numbers are those shown on the map, Pl. 7, except where otherwise stated.

yielded only one fossil (from loc. 40) which can only be identified as a diplograptid or climacograptid. Keratophyric flows are developed on a small scale and are seen at loc. 225. The lower tuffs and lavas are seen only in the most westerly of the fault blocks into which the area is divided. To the east beds below the autobreccia are drift-covered.

The Basaltic Group is well seen in the stream and on the hill to the north of Grangegeeth crossroads, but like the underlying rocks has not been traced in the fault blocks lying further east. Its maximum thickness is about 100 feet.

The Brecciated Keratophyres are the most prominent rocks in the succession from a topographical point of view, as they form most of the highest ground—the hill to the north of Grangegeeth, the rocky ground of Clogher Wood, and the high ground to the south and north of Collon (Collon Windmill and an area of rough ground stretching from Mellifont Abbey Gate on the Ardee Road in Collon Village to Black Hill). These hills show a rocky face to the west but outcrops disappear eastwards in each case under a tail of drift. The shifting of the outcrop of this rock has made the dip-faulting of the area evident. The six-inch field maps of the Irish Geological Survey show these faulted masses of autobreccia as lens-shaped outcrops placed *en echelon*. It is interesting to note however that Du Noyer wrote in manuscript on the back of one of these six-inch sheets that the Clogher Wood and Collon Windmill rocks " are similar and highly probably connected." Of the three editions of the one-inch map 91 the first terms the keratophyre a " greenstone," the second a " felsite and felspathic ash," and the final edition in 1901, most surprisingly and erroneously, " Llandovery with conglomerate." The latter misconception probably arose because at loc. 5 the base of the Upper Tuffs contains rounded fragments of keratophyre and fossils then supposed to be Llandovery. The Keratophyre Group thins from north to south. At Collon the outcrop is some 1,300 yards wide, which assuming* a dip of 30° gives a thickness of nearly 2,000 feet. At Grangegeeth in the most westerly block the width of outcrop is only 220 yards ; the overlying and underlying beds dip at about 30°, so that the thickness here is about 330 feet. It is remarkable that in the stream just west of the road running north from Grangegeeth the autobreccia which forms the autobrecciated keratophyre has entirely disappeared and keratophyric tuffs occur on the same strike. This does not mark the termination of the autobreccia outcrop for it reappears, apparently shifted southwards by another fault, just outside the area about half a mile southwest of Grangegeeth. There is a possibility that the great thickness at Collon may be due to strike faulting, but there is no evidence of this.

The Upper Tuffs and Shales. North of Grangegeeth at locs. 1 and 3 are two small quarries showing hard greenish-grey tuffs which weather brown, dipping southwards at 30° off the keratophyre. No junction is seen. They are moderately well bedded, and where weathered yield a large fauna consisting predominantly of brachiopods in the form of moulds which are in an excellent state of preservation ; both quarries are at the same horizon, although that at loc. 3 also shows slightly

*The quarry north of the windmill stump showed " hardened gray grits" (presumably tuffs) dipping south at 40° (Hull, Leonard, and Baily, 1871, p. 29).

lower and more massive beds in which the fauna is similar. Small irregular fragments of the keratophyre are occasionally seen in the tuffs.

The faunas from the two localities are listed below. (Survey Locality No. 1 (Hull, Cruise, and Baily, 1871, p. 13), corresponds to the present locality 1).

r. *Nidulites favus* Salter (s.)
r. *Pyritonema* sp.
Crinoid stem-columnals.
r. *Cheirocrinus* plate (s.)
c. *Actinonema subarachnoidea* (Reed).*
m. *Catazyga anglica* (Davidson)*.
c. *Hesperorthis inostrantzefi* (Wysogorski)*.
r. *Kullervo* sp.*
r. *Leptelloidea* aff. *grayae* (Davidson).
m. *Leptestia jukesi* (Davidson)*.
r. *Lingula amabilis* Reed (s.)
r. *Lingula brevis* var. *angustior* Reed (s.)
c. *Ŏpikina bailyi* sp. nov.*
m. *Ŏpikina celtica* sp. nov.*
r. *Ŏpikina girvanensis* (Reed)* (s.)
r. " *Orthis* " *confinis* Salter ? (s.)
c. *Oxoplecia* cf. *andersoni* Reed.
r. *Plaesiomys* cf. *thraivensis* (Reed), resembling that figured by Reed from Pomeroy. (Proc. Roy. Irish Acad., 55 Pl. 1, fig. 6, in the press).
c. *Platystrophia* sp.
r. *Pseudocrania divaricata* (McCoy) (s.)
c. *Rafinesquina concentrica* (Portlock).
m. *Sowerbyella sericea* (Sowerby) var. *brynensis* Whittington.
r. *Conocardium dipterus* Salter (s.)
r. *Raphistoma* sp.
r. *Barrandeoceras* sp. (kindly identified by Dr. R. Flower).
r. *Cybele* (*Cybelella*) cf. *rex Nieszkowski.**
r. *Illaenus richardsoni* Reed.*
r. *Lichas* (*Acrolichas*) *hibernicus* (Portlock).
r. " *Phacops* " *kuckersianus* Schmidt (s.)

Similar bedded tuffs are seen here and there for nearly a mile eastwards of the above-mentioned localities, but fossils are not common, and lithology tends to be variable, the tuffs sometimes becoming muddy. In places they are slightly calcareous. At loc. 5, about one-third of a mile northeast of Grangegeeth the tuffs contain rounded fragments of the underlying keratophyre and pieces of black shale, and would appear to be almost at the base of the Upper Tuff and Shale group. Fossils

r. rare, m. fairly common, c. common, (s) in Geological Survey of Ireland collections, but not collected by author.

*These fossils are further dealt with in the palaeontological section of this paper.

occur, but they are poorly preserved and not common. The following have been found :—

Crinoid stem columnals.
Hesperorthis inostrantzefi (Wysogorski).
Platystrophia sp.

The presence of these pebbles of keratophyre, which are usually visible only in thin section, suggests an erosional break at the base of the Upper Tuffs and Shales. In this connection the sudden absence of keratophyre immediately north of loc. 1 may be significant. There is no evidence of faulting in the keratophyre as the basalts below it continue without a break, and the tuffs above in the quarries, locs. 1 and 3, show no sign of a break between them. Whether this thinning of the keratophyre is due to deposition on an erosional feature or on an original surface irregularity it is not possible to say. It may be that the tuffs north of locality 1 are part of the keratophyre series, and are older than the Upper Tuffs and shales.

In the brook further east at loc. 25 coarse and fine calcareous tuffs with a few fossils are seen. The following forms have been found there :—

(1) *Pyritonema* sp.
(2) Crinoid stem-columnals.
(3) *Ptilodictya dichotoma* Portlock.
(4) Fragments of ribbed brachiopods.

At an exposure, loc. 26, in an old quarry one and one-third miles east-southeast of Grangegeeth much-weathered dull brown shales are exposed. Their position suggests that they are at a slightly higher horizon than the fossiliferous tuffs, but their fauna, although not like that of the tuffs, indicates a similar age. The following forms have been recognised :—

(1) *Barbarorthis* sp.
(2) *Chonetoidea* sp.
(3) *Sowerbyella semirugata* (Reed).
(4) *Acidaspis* (*Onchaspis*) cf. *lalage* Wyville Thomson.*
(5) "*Agnostus*" *girvanensis* Reed.*
(6) *Proetus ardmillanensis* Begg.*
(7) *Primitia* sp.

In the Clogher Wood fault block no exposure of Upper Tuffs and Shales is seen, but fortunately material from a series of holes dug by the Electricity Supply Board yielded some fossils in the townland of Broomfield. At loc. 22, grey, brown-weathering, mudstones yielded a cyclopygid eye and a poor specimen of *Orthograptus* sp. Loc. 23 showed yellow-weathering tuffs which yielded a fossil belonging to a genus previously unknown to Ireland and rare in the British Isles, viz., *Kullervo hibernica* sp. nov. At loc. 38, about half a mile south of Collon, buff-weathering shales are exposed, and one specimen of *Cybele* cf. *revaliensis* Schmidt, was obtained.

*Described in palæontological section.

In the Collon fault-block greenish tuffs and fine micaceous hard yellow and often blotched or streaky mudstones are seen in the stream running through Fiddle Wood to the southeast of Collon, and at Starinagh at the top of the Wood yellowish mudstones have yielded to the Irish Geological Survey fragmentary trilobite remains (specimen in G.S.I. Collection). At loc. 56 in the farmyard at Starinagh a thin band of black graptolitic shales yielded *Climacograptus brevis* Elles and Wood, *C. minimus* Carruthers, and *C. styloideus* Lapworth, an assemblage which suggests the zone of *Dicranograptus clingani* or *Pleurograptus linearis*. It is probable that this represents a transition into the succeeding black shales of Broomfield described below. The thickness of the Upper Tuffs and Shales can be tentatively put at about 1,000 feet.

The brown shales of Mellifont. Mellifont Abbey lies about three quarters of a mile north-northeast of Collon village, and on all except the most recent six-inch maps is known as Oriel Temple. The latter became a monastery about 1938, and was renamed New Mellifont, but is now known as Mellifont, and is not to be confused with the well-known ruin of the same name which lies about two and a half miles to the southeast of Collon. Brown weathering shales are seen in and around the farmyard of the Monastery (called " The Grange " on the six-inch map).

In a temporary exposure immediately to the eastern side of the farm buildings (loc. 30), a sparse fauna of poorly preserved fossils was obtained including *Climacograptus* sp., *Sowerbyella* sp., *Pseudobasilicus* sp. (see p. 108), and crinoid stem-columnals. A similar fauna, without the graptolites, was found 270 yards to the north at loc. 44. To the north of the farm was an old quarry, now filled in, which is loc. 8 of the Survey Memoir (present loc. 246). This quarry was seen some years ago by the author, but was already very overgrown. It showed brown-weathering shales, which did not yield any fossils, and a small outcrop of keratophyre whose relation to the shales was not visible. The Geological Survey Memoir (Hull, Leonard and Baily, 1871, p. 29), lists from the brown shales at locality 8 the following fossils, none of which has been traced to the collections of the Irish Survey :—*Favosites fibrosus, Diplograptus pristis, Glyptocrinus* sp., *Agnostus trinodus, Aeglina mirabilis, Beyrichia complicata, Remopleurides* sp., *Crania divaricata, Leptaena sericea, Orthis biforata, O. calligramma.* Salter figures from Collon (1866 b, pl. xviii, figs. 4 and 5), *Asaphus radiatus,* which the present author refers to *Pseudobasilicus* sp. (see p. 108). The specimens figured by Salter are in the collections of the British Geological Survey, and show lithology similar to that just described. Other exposures are seen to the north of the brecciated keratophyre on Black Hill, and near the boundary with that rock nearly half a mile south of the Grange, where fossil fragments occur. They were also met with in a bore for water under 85 feet of drift some 470 yards south of the Abbey by the side of the drive from Collon Village. At the Grotto, blotchy mudstones similar to those seen in Fiddle Wood in the Upper Tuffs and Shales are seen, but the relation of this isolated exposure to the brown shales is not known.

From the field evidence it is not possible to assess the stratigraphical position of the brown shales of Mellifont. The Survey Memoir lists from loc. 8 the following brachiopods, which were also identified from Survey locality 1 in the Upper Tuffs and Shales at Grangegeeth (Hull, Cruise and Baily, 1871, p. 16) :—*Crania divaricata,*

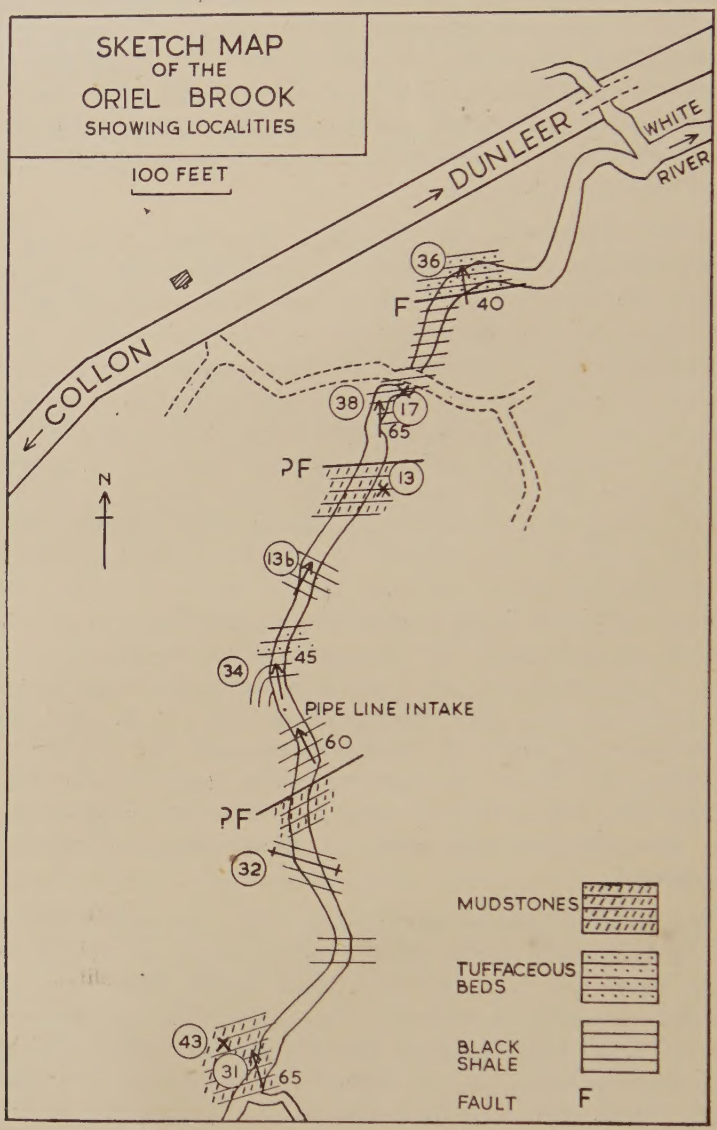
Orthis calligramma, and *O. biforata*, a group of fossils which is of no great help in correlation in view of the date of identification. The author, at loc. 26 (Upper Tuffs and Shales) has found agnostids and fragmentary asaphid pygidia. Agnostids are recorded in the Survey list from loc. 8, and Salter's "*Asaphus radiatus*" mentioned above is almost certainly from that locality. With this faunal information it is unwise to make any dogmatic statement, but the author is inclined to the opinion that the brown shales of Mellifont are similar in age to the Upper Tuffs and Shales. Their lithology is certainly unlike any seen under the basalts in the Grangegeeth district. If this is so then the brown shales must be faulted against the keratophyre. They usually have a high dip (50°—70°) to the south, towards the keratophyre, and at loc. 39 are considerably shattered.

The Black Graptolitic Shales of Broomfield. These are well exposed in the large quarry on the boundary of the townlands of Broomfield and Glassallen (loc. 60), and in the lane cutting to the east. Black cherty bands,* usually about a quarter to one inch thick, with fine shaly carbonaceous partings are seen. In the quarry they are much contorted and broken, but in the lane they are less disturbed and have a general steep dip to the southeast towards the Silurian which is exposed less than 300 yards away. The beds have slipped along the shaly partings. Graptolites are found in the shaly partings, and in the siliceous bands but are poorly preserved. The author has identified the following species :—*Cl. brevis*, *C. caudatus* Lapworth, *Dicellograptus morrisi* Hopkinson, *D. pumilus* Lapworth, *Orthograptus calcaratus* var. *basilicus* Lapworth, *O. pageanus* Lapworth. This assemblage indicates the zone of *Dicranograptus clingani*. Baily (1859, p. 124), refers to the black shales at "Glenallen," and compares them with the black shales at the Commons of Slane, two miles south of Grangegeeth, noting the presence of small horny brachiopods at both localities. The fauna from the Commons of Slane in the G.S.I. collections was submitted to Dr. O. M. B. Bulman, who has identified *Climacograptus brevis*, *Cl. minimus*, *Cl. styloideus*, *Dicellograptus morrisi* and *Orthograptus truncatus pauperatus* Elles and Wood. He is of the opinion that the zone of *P. linearis* is probably indicated. The lower and upper boundaries of the shales are not seen at Glassallen. Their thickness is impossible to estimate owing to the contortion which they have suffered.

The Oriel Brook Mudstones (see map in text). An interesting section is seen about two-thirds of a mile east of north of the Monastery, in an unnamed tributary of the White River here called the Oriel Brook, which gives a 300 yards exposure of black shales and some beds believed to be younger than any seen elsewhere in the area which are here termed the Oriel Brook Mudstones. They are seen about 350 yards south from the bridge over the White River on the Collon-Dunleer road, where an old quarry on the left bank of the stream (loc. 43) shows grey, greenish-weathering mudstones. Fossils are uncommon, but a few were found in an impersistent earthy band, viz. :—*Trinodus tardus* (Hawle and Corda), *Cyclopyge* cf. *rediviva* (Barrande), and ? *Symphysops subarmata* (Reed). Similar mudstones are seen at the stream's edge at loc. 31, where they dip northwest at 65°. Fossils found there include a

*Some of these cherty bands show, in thin section, circular cavities filled with quartz. It is possible that these may have been radiolaria, but no structure can be seen.

trinucleid fragment, *Sowerbyella* sp., and *Primitia* sp. Downstream exposures are poor for about 90 yards, and consist of a few outcrops of black shale, usually silicified, until a small waterfall with a pool below is reached (loc. 32), where black cherty shales occur with poorly preserved graptolites, including *Climacograptus*



caudatus and *Dicranograptus* sp. Below the pool is a short break in the exposure, and then grey, greenish-weathering mudstones are seen in the stream and in a quarry in the right bank. No dip can be seen, and fossils were not discovered. The lithology is like that at locs. 31 and 43 (see above), and that at loc. 13 (see below). A lamprophyre dyke then crosses the stream, and black shales come on almost at once (loc.

34) a few yards above the point where a pipe-line leaves the stream. The black shales dip northwest at 60° and have yielded a fauna of graptolites indicating the zone of *Pleurograptus linearis*. This fauna includes *Cl. styloideus*, *Dicellograptus pumilus*, *Leptograptus flaccidus* Hall, *L. flaccidus macer* Elles and Wood, and *Orthograptus truncatus pauperatus* ; disturbed beds follow, and then the dip of the black shales swings round to the northwest at 45°, just below the point at which the pipe-line leaves the stream. In the left bank, the shales are seen to grade up into pale banded tuffaceous beds, and in about 50 yards, after passing a series of vertical dark grey striped shales, black graptolitic shales cross the stream dipping northwest at 80° (loc. 13b). The graptolites include *Climacograptus bicornis* Hall, *Dicellograptus morrisi*, *Leptograptus* sp., *Orthograptus calcaratus basilicus*, *O. truncatus pauperatus*. This fauna suggests a horizon slightly lower than that at loc. 34, at the top of the *D. clingani* or base of the *P. linearis* zone. Exposures are poor for the next 35 yards, consisting of occasional outcrops of soft grey shales and paler shales with dark blots or streaks, until tough, grey, greenish-weathering mudstones are seen at loc. 13 about 30 yards above a foot bridge in the stream, and in a quarry on the right bank. No dip can be seen and fossils are few and scattered, usually fragmentary and small ; the following have been identified :—

Trinodus tardus (Hawle and Corda).
Cyclopyge cf. *rediviva* (Barrande).
Cyclopyge bumasti (Reed).
Phylacops cf. *vigilans* Cooper and Kindle (resembling that referred to by Reed 1952, in the press).
Tretaspis sp.
Primitia sp. and a plectambonitid.

These beds are like those seen at locs. 31 and 43, both in lithology and fauna. Downstream steeply dipping grey mudstones are seen, rather poorly exposed. Their relation to the fossiliferous mudstones at loc. 13 is not evident. These are followed by soft black, smooth-weathering shales with *Climacograptus styloideus*, and just above the point where the stream turns abruptly east (loc. 38), black pyritic rather poorly-bedded mudstones are seen dipping north at 50°—60°. These contain the following graptolites :—*Climacograptus minimus*, *C. styloideus*, *Orthograptus calcaratus basilicus*, *O. truncatus pauperatus* indicating a *clingani* or basal *linearis* horizon. In the short, straight stretch of stream immediately above the foot-bridge (loc. 17), the exposure is continued, showing vertically bedded black graptolitic shales striking slightly north of east. Graptolites found were *Dicellograptus morrisi*, *D. pumilus*, *Orthograptus calcaratus basilicus*, suggesting a horizon similar to that of loc. 38. Below the foot bridge black cherty shales, almost vertical and somewhat broken, have yielded a few poorly preserved graptolites including *Orthograptus* sp. and *Dicellograptus* sp. About 35 yards below the bridge at a small pool, a rotted lamprophyre dyke occupies a fault which separates black shales upstream from pale, almost white very finely banded tuffaceous beds (loc. 36), which have marked spheroidal weathering and break along the bedding with difficulty. In some bands are numerous very poorly preserved graptolites, but a few good specimens include *Climacograptus brevis*, *Cl. minimus*, and a species of *Diplograptus* which Dr. Bulman considers has

some resemblance to *D. leptotheca* Bulman of the Laggan Burn Limestone of Girvan. No further exposures are seen below this point.

The black shales in this section all seem to be at approximately the same position, i.e., the *P. linearis* zone or possibly in some cases the top of the underlying zone of *D. clingani*, and they must therefore correspond at least in part to the black shales seen at Broomfield (loc. 60), and Starinagh (loc. 56). It is unfortunate that their relation to the Oriel Brook Mudstones is never seen. It is probably a faulted one. The fauna of the mudstones resembles that of the Upper Whitehouse beds of Girvan, which are of *D. complanatus* age, and it seems likely therefore that the Oriel Brook Mudstones are younger than the black shales. At Broomfield and Starinagh no beds which suggest the lithology of the Oriel Brook Mudstones are seen below the black shales, and it is reasonable to suppose that the latter are of post *P. linearis* age.

Structure.

The boundaries of the area are lines of faulting, Ordovician strata being surrounded on three sides by Silurian. On the west, although no junction is seen, there is little doubt from the straight course of the boundary that there is a fault running northeast-southwest, downthrowing Silurian banded mudstones and grits on the western side. If produced to the southwest this fault would pass near Navan, and along its course separates rocks with volcanics (Ordovician) on its eastern side from rocks without volcanics (presumably Silurian) on its western side. South of Navan it passes under the unconformable cover of Carboniferous. At its northeastern end, north of Collon, it would pass under the drift-covered plain north of Ardee. The southern contact of the Ordovician rocks is also a line of fault. Just off the map, about half a mile south of Grangegeeth, flaggy grits and mudstones with Silurian graptolites are seen dipping steeply towards Ordovician volcanic rocks nearby. The graptolites indicate that the Silurian is of top Valentian or low Wenlock age. At Glassallen crossroads flaggy Silurian beds are seen dipping away from contorted black graptolitic shales of *clingani-linearis* age. The eastern boundary of the area is obscured by drift over a wide area. It is possible that some evidence of the nature of this boundary may be obtained from the area to the south.

The structure in the Ordovician itself is clear in broad outline if the autobreccia is regarded as one horizon. The Irish Geological Survey Officers did not recognise this, but there does not seem any reason to doubt that it is, in fact, at one horizon, and does not represent several isolated flows. The country is divided into four blocks by dip faults which cause the outcrops to be shifted northwards at each fault as one passes from west to east. This is made obvious by the displacement of the autobreccia, but would be difficult to recognize from the behaviour of the other beds owing to the poor exposures. The sudden change in the width of the outcrops of the keratophyres at some of the faults, gives the impression that each fault downthrows to the east and that the lava probably thinned southwards. The only strike faulting recognized in the area is that at Collon on Black Hill, where shaly beds, believed to belong to the Upper Tuffs and Shales, are brought against the autobreccia. The relations of the beds within the blocks are not easy to see in the field except in the western block, where the dip of the tuffs above and below the keratophyre is fairly steady to the south at 20°—30°.

The black shales at Broomfield, which overlie the Upper Tuffs and Shales, are violently contorted and broken, and those of the Oriel Brook show sharp folding along axes running slightly north of east. Cleavage is rarely seen in the area, but is quite well developed in the brown shales at Mellifont, especially at the localities around the Grange, where it dips in a southeasterly direction at 70°—80°.

COMPARISON WITH OTHER AREAS.

(*a*) *The Ordovician succession* in Ireland has recently been summarized by the author (Harper, 1949, pp. 48–67), and it is intended here to refer only to exposures in Ireland between Dublin and Drogheda and at Kildare and Pomeroy. As indicated in the introductory remarks the Ordovician outcrops continue south of the described area towards Slane. Exposed rocks are mainly lavas and tuffs, but graptolitic shales occur at the Commons of Slane. Irish Geological Survey specimens from the latter locality were submitted to Dr. Bulman, who is of the opinion that the beds probably belong to the *P. linearis* zone. A small faulted inlier of black cherty shales surrounded by Silurian beds occurs near Mountfortescue about one mile to the northwest of Grangegeeth. About twenty miles to the southeast at Balbriggan shales with a Caradoc fauna are associated with a thick series of andesites and tuffs. Between Balbriggan and Grangegeeth, around Bellewstown and Duleek, mudstones with Llanvirn graptolites occur. Some Irish Geological Survey specimens from there were submitted to Dr. Bulman, who concludes that the *Didymograptus bifidus* zone and probably portions of the underlying and overlying zones are present. These graptolitic mudstones are apparently overlain by shales with a shelly fauna of Bala age, which are associated with volcanic rocks. Black shales, lithologically like those of Broomfield, occur in the succession (Baily, 1862, pp. 300-302 ; Hull, Cruise, and Baily, 1871, pp. 26–29, 30–32).

Further south at Portrane and Lambay Island similar volcanic rocks are associated with sediments containing a Caradoc fauna.

At Kildare tuffs and shales occur with what is probably a Caradoc fauna, and these overlie Llanvirn beds carrying *Didymograptus bifidus*. To the north of Collon the only important shelly faunas occur at Pomeroy, Co. Tyrone. Here the Tyrone Igneous Series, which have been compared with the Arenig Volcanics of the Highland Border, are found to consist mainly of basic lavas and tuffs with some andesites. Graptolites found in the tuffs suggest a horizon not higher than Lower Caradoc. On this series the Bardahessiagh Beds, thought to be of Balclatchie age (Stubblefield, 1939, p. 60, Whittington, 1950, p. 27 and 28), rest unconformably. The succeeding beds are the Killey Bridge Beds and the Tirnaskea Beds. The Tirnaskea Beds contain *D. complanatus* in their lower part and *D. anceps*, associated with a cyclopygid—agnostid fauna, in their upper part. There is no evidence that this last fauna is at such a high horizon in the Oriel Brook section.

It is thus evident that on the eastern side of Ireland there is a widespread and often thick volcanic series consisting dominantly of andesitic lavas associated with, or overlain by, beds with a Caradoc fauna, and underlain in places by rocks of Llanvirn age, the youngest recognised underlying graptolitic fauna belonging to the

D. bifidus horizon or slightly higher. In the Lake District of England the Skiddaw Slates, which range as high as the *D. bifidus* zone, are overlain by the Borrowdale Volcanic Series, which are dominantly andesitic. In Ireland, at Portrane, Lambay, and Kildare, the volcanics are followed by shallow-water limestones, and in the Lake District the Borrowdale Series is followed by the Coniston Limestone. It appears therefore that the eastern Irish Ordovician volcanics occupy a stratigraphical position equivalent in a general way to that of the Borrowdale Volcanics, and are often followed, as in the Lake District, by a group of shallow water calcareous sediments ; the age relationships of the latter are not certain and may range from Caradoc to Ashgill.

(*b*) *The faunal relationships* of the Grangegeeth district can now be considered. The fauna of the Upper Tuffs and Shales has several points of interest. Firstly, it is obvious that among the brachiopods and trilobites a convincing comparison can be made with the Balclatchie Beds of Girvan. The following species occur in both areas :—*Lingula amabilis, Lingula brevis* var. *angustior, Rafinesquina concentrica, Sowerbyella semirugata, Actinonema subarachnoidea, Öpikina girvanensis, Illaenus richardsoni, Lichas* (*Acrolichas*) *hibernicus, Proetus ardmillanensis* and *" Agnostus " girvanensis*. In addition there are several forms from Grangegeeth which are closely allied to Balclatchie fossils such as *Oxoplecia* cf. *andersoni, Leptelloidea* aff. *grayae, " Acidaspis "* cf. *lalage* and others. It has been suggested that the Bardhahessiagh Beds of Pomeroy are of Balclatchie age (Whittington, 1950, pp. 27-28). Stubblefield (1939, p. 60), has pointed out that, of the trilobite species occuring in these Irish beds, two are found in the Balclatchie Beds. This correlation is hardly supported if one considers the brachiopods as revised by Reed (1952, in the press), who describes about a dozen brachiopods said to occur in the Bardahessiagh Beds ; he notes American or Norwegian (Hovin Group) affinities for many of these, and no fewer than five he identifies with Drummuck Bed forms, whereas two are identified with Balclatchie species.

Two species, *Rafinesquina concentrica* and *"Lichas" hibernicus* are common to Bardahessiagh Beds, Balclatchie Beds, and the Upper Tuffs and Shales of Grangegeeth.

The present author is inclined to accept the trilobite evidence, and regard the Bardahessiagh Beds as being of Caradoc age.

It has been mentioned above that shallow water limestones followed a volcanic phase in Eastern Ireland and the Lake District ; limestones of Bala age are also known in boulders from the Carboniferous of the Isle of Man. It is likely that shallower waters existed all along this stretch during the accumulation of volcanic products and may have provided a route for migration via some point in the more easterly part of the Southern Uplands ; it may be noted that although in the west of the Southern Uplands black shale deposition was continuous from *N. gracilis* to *D. anceps* time, in the central region north of Peebles a shelly fauna occurs in limestone breccia (the Wrae Limestone) which possibly has Balclatchie affinities. The limestone is overlain by ashes which contain black shales, indicating a high *D. clingani* horizon. To the northeast of this district along the strike it is interesting to notice that there is no record of rocks earlier than *P. linearis* in age, so that the nature of

the underlying rocks is unknown. Possibly a shallow-water belt may have stretched from the Lakes towards Peebles, giving correlation with shallow littoral deposits to the north in pre-*P. linearis* times, allowing connection with Girvan.

The last point to be noted is the presence in the Grangegeeth fauna of several forms which are close to species occuring in the Kuckers Series of Esthonia. In one case there appears to be specific identity, viz. :—*Hesperorthis inostrantzefi.* Forms which are close to Esthonian species are *Kullervo hibernica* sp. nov. a representative of a genus unknown from Britain except for *K. albida* (Reed) in the Whitehouse Beds of Girvan. The genus has been recorded from the Whitehead Limestone (Upper Ordovician) of Quebec in *K. pyramidata* by Cooper and Kindle (1936, p. 353). *Leptestia jukesi* (Davidson), unknown even generically at Girvan, is close to *L. musculosa* Bekker of Esthonia, and *Öpikina* spp. have near relations at Girvan, Esthonia, and in the Mohawkian of North America. *Catazyga anglica* (Davidson), the only spire-bearing brachiopod recorded, is not known from Girvan, but has closely related forms in the English Head and Lorraine of Anticosti and the Whitehead of Quebec. The *Cybele* spp. recorded are close to Esthonian forms. Reed has noted (1906, p. 175), the presence of the Baltic element in the Ordovician succession at Girvan as regards the trilobites, but remarks (1917, p. 969) on the American rather than North European affinities of the brachiopod and bellerophontid fauna. It is likely that a revision of the Balclatchie brachiopods would show that the Baltic affinities are greater than Reed thought. Reed in his revision of the Pomeroy fauna (1952, in the press) does not shed as much light on the distribution of faunas as could be wished, as the exact horizon of many of the fossils are not given. The cyclopygids and agnostids in the higher beds of the Oriel River recall the forms described by Reed (1952, in the press) from the Tirnaskea Beds of Pomeroy. The latter are said to be associated with *D. anceps* (Fearnsides and others, 1907, p. 104). The Girvan cyclopygid fauna occurs at the lower horizon of *D. complanatus*, in the Upper Whitehouse Beds ; in the Oriel River it is either in the *linearis* zone or higher, but, as has been explained, faulting makes exact correlation impossible. A Whitehouse fauna occurs in Co. Clare just above beds with *D. complanatus*.

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Palæontology.

Actinonema Öpik

Actinonema subarachnoidea (Reed).

Pl. 6. Figs. 4, 5.

Rafinesquina subarachnoidea Reed, 1917, pl. xii, figs. 25–30, *non* 31 ;
Actinonema subarachnoidea Öpik, 1930b, p. 166.

This variable species first described by Reed (op. cit., p. 870), from the Balclatchie Beds of Girvan is common at Grangegeeth. It is here refigured for purposes of comparison and because the interior of the ventral valve, which Reed did not describe or figure, is now available from Grangegeeth.

Material G.S.I./J.C.H. 6*. Exterior of ventral valve, N.M.I. 1951/16. Internal mould of ventral valve.

Locality and Horizon 1 and 3. Grangegeeth Volcanic Series. Upper Tuffs and Shales.

The external details correspond with those described by Reed. The shell is flattened, the hinge equal to or slightly greater than the greatest width of the shell. Small sharp umbo. Hinge straight and produced into slight ears. Ornament of about 10 fine thread-like ribs with secondaries in between arising by intercalation at about half length. Fine radial striæ in interspaces. A few concentric rugae in the hinge region. The interior of the ventral valve shows a narrow apsacline area, with dental plates diverging at slightly less than 90°. Narrow parallel-sided diductor impressions are bounded by distinct ridges which run at right-angles to the hinge from the end of the dental plates to about one-quarter the length of the shell. The adductor impressions are narrow and indistinct. Radial markings extend from the hinge region near the umbo for a short distance, and are crossed by a few concentric rugae. A few radial grooves extend for a short way from the anterior border.

Remarks.—This species is known from the Balclatchie Beds, and the genus is known from the Pomeroy Ordovician and from the Kuckers and higher Ordovician and the Silurian of Esthonia.

Catazyga Hall and Clarke.

Catazyga anglica (Davidson).

Pl. 6. Figs. 15–18.

Athyris headii var. *anglica* Davidson, 1866, pl. xxii, figs. 1–7a, 8a, 8b.
Zygospira anticostiensis Davidson 1889, p. 127, 128.

Material. Seven specimens are present on one tablet in the G.S.I. Collections labelled "*Atrypa anticostianis*"; five are internal moulds, and two show external details. Davidson based his variety on six syntypes, five of which were from Grange-

*The following contractions are used :—specimens in collections of the Geological Survey of Ireland, G.S.I. ; National Museum of Ireland, N.M.I. ; Geological Survey of Great Britain, G.S.M. ; Hunterian Museum, H.M. ; British Museum, B.M. ; University of Liverpool, L.U.

geeth and one from Shropshire. It is considered that the originals of Davidson, pl. xxii, figs. 2, 4, 6, and 7 are present. The Shropshire specimen, the original of Davidson's, fig. 8, is in the British Museum (B.M. B7894).

Lectotype (here chosen), G.S.I./J.C.H. 3 (original of Davidson, pl. xxii, fig. 2). Internal mould of dorsal valve.

Other material. G.S.I./J.C.H. 4 (possibly original of Davidson, fig. 4). Internal mould of ventral valve. G.S.I./J.C.H. 2136 (original of Davidson, fig. 6). Internal mould of ventral valve. G.S.I./J.C.H. 5 (original of Davidson's, fig. 7). Internal mould of dorsal and ventral valves. G.S.I./J.C.H. 7. Exterior of dorsal valve.

Locality and Horizon. Upper Tuffs and Shales. G.S.I. Loc. 1, Grangegeeth.

General outline of the shell rounded, valves moderately convex. Ornament consisting of about 50 fine ribs. No sinus on the ventral valve; internally the dorsal valve shows a well-defined median septum, reaching to about half way to the anterior margin, with two long, deep, and narrow adductor impressions running parallel to it, but not quite as long. Adductors bounded laterally by two quite well-defined septa. Hinge details not preserved. Interior of ventral valve shows a slightly curved hinge line with an orthocline area. In G.S.I./J.C.H. 2136 there is a flattened triangular region in the hinge area bearing the muscle impression, which is separated by what is almost a geniculation from the rest of the shell. This abrupt change of convexity is not so marked in G.S.I./J.C.H. 4. In the ventral valve the adductor impressions form a deep narrow parallel-sided cavity which extends to the change of valve curvature at about one-third the length of the shell. On either side are the narrow diductor impressions which are strong, but not as deeply impressed as the adductor and only about half its length. G.S.I./J.C.H. 5 is a smaller lenticular shell, but shows similar impressions and may be a young individual.

Remarks. When Davidson referred his material to *Zygospira anticostiensis* Billings (1889, p. 127), in his final line he nevertheless referred to " the Irish variety *anglica* " being common at Grangegeeth as if he still wished the Irish form to remain a separate variety.

Hall and Clarke (1894, p. 157) refer to *C. anticostiensis* as having a keeled ventral valve and a broad sinus on the dorsal valve. Twenhofel (1928, p. 215), states that *C. anticostiensis*, in which he included the Irish variety, has a ventral fold at the beak, and a dorsal sinus. It is said to have 30–35 ribs; the Irish material does not show these features. Twenhofel gives no account of internal characters. Reed (1932, p. 125) in referring a shell from the Hovin Sandstone of Norway to *C.* cf. *anticostiensis* remarks on the resemblance of his specimens to the Irish material.

In view of some discrepancies in external details, and the absence of information on the interior of *C. anticostiensis*, the author prefers to retain Davidson's name of *anglica*, and to raise it to specific rank. *C. cartieri* Cooper and Kindle, of the Whitehead Formation of Percé, Quebec, bears a close resemblance externally to the Irish form in its contour and the number of ribs.

HESPERORTHIS, Schuchert and Cooper.

Hesperorthis inostrantzefi (Wysogorski).

PL. 5. FIGS. 8–10.

Orthis inostrantzefi Wysogorski, 1900, p. 232.
Orthis inostrancefi Öpik, 1930a, p. 13, pl. iii, fig. 6.
Orthis inostrancefi Öpik, 1930b, p. 65, pl. i, fig. 2–9, 11.
Hesperorthis inostrantzefi Schuchert and Cooper, 1932, p. 86.

This species, fully described by Öpik (1930b, p. 65), from the Kuckers Shale of Esthonia, is abundant in the Upper Tuffs and Shales at Locs. 1 and 3 at Grangegeeth. It is figured here, as it has not been recorded from the British Isles before. *Orthis calligramma craigensis*, Reed, from Girvan, which Öpik referred (*loc. cit.*) to *H. inostrantzefi*, is, as Reed (1935, p. 347) stated, more likely to belong to *Barbarorthis*. It is certainly not conspecific with *H. inostrantzefi*. One Grangegeeth specimen from Loc. 26 (L.U. 7020, 7020a) has ornament similar to *Barbarorthis craigensis* Reed, but is not of the same dimensions.

The specimens figured here from Grangegeeth are N.M.I. 1951/9, 1951/10, 10a, and there is other material in the G.S.I. collections and at the University of Liverpool.

KULLERVO Öpik.

Kullervo hibernica sp. nov.

PL. 6. FIGS. 6–8.

Material. The material consists of the internal mould of a dorsal valve and the corresponding external impression. Also the external impression of a dorsal valve. There is in the collections of the Geological Survey of Ireland an internal mould of a ventral valve which may belong to this species (G.S.I./J.C.H. 2089). Another dorsal valve (internal mould and external impression) has been presented to the British Museum.

Locality and Horizon. N.M.I./1951/18, 18a, 19. Upper Tuffs and Shales, Loc. 23. G.S.I./J.C.H. 2089. Upper Tuffs and Shales, G.S.I. Loc. 1, Grangegeeth

Holotype. N.M.I. 1951/18 and 18a. Dorsal valve external impression and internal mould.

Paratype. N.M.I. 1951/19. Dorsal valve external impression.

Dimensions.

	Hinge width mm.	Length mm.
N.M.I. 1951/18	14.9 (est.)	9.0
N.M.I. 1951/19	15.0	8.0

The dorsal valve externally shows a long straight hinge with inconspicuous umbo. Slight pointed ears. General shape of shell subquadrate; slightly convex with flattening over ear region. Faint median sinus. Ornament of numerous fine ribs increasing by interpolation at about half length. Ribs absent or much less

strong over region of ears. The whole shell is covered with raised, slightly scaly, concentric ornament. The interior of the valve is unfortunately incomplete, but in those characters which are visible it resembles *K. panderi* Öpik closely. The muscle scars are well impressed, the raised edges of the anterior ones being even more strongly impressed in the Irish form. The radially grooved marginal region is wider in *K. hibernica*, and the muscle impressions just reach to it, thus extending about half the length of the shell, whereas in *K. panderi* they reach about three-quarters of the way to the anterior margin. The median septum is wide and low posteriorly but becomes narrow and sharp between the anterior adductors. A single internal mould of a ventral valve which has the character of *Kullervo* is present in the Irish Geological Survey Collections (G.S.I./J.C.H. 2089). It is labelled "*Orthis calligramma*," and presumably, from the lithology, comes from Survey Locality 1. It is radially grooved nearly to the hinge, and is comparable in this respect to *K. panderi* Öpik (1934, pl. xxxv, fig. 5). There is a small spondylium, with two or three radial ridges on its dorsal surface, supported on a small low median septum which projects slightly beyond it anteriorly.

Remarks. Several species of *Kullervo* are recorded by Öpik (1934, pp. 162–173) from the Kuckers of Esthonia. *K. complectens* (Wiman), is known from the Leptaena kalk of Öland and possibly occurs also in the Lyckholm of Esthonia (*op. cit.* p. 174). The only British species referred to this genus is *Clitambonites complectens albida* (Reed) (*op. cit.*, p. 164). The Irish species seems to differ from the Baltic species in the fineness of its ribbing and the comparative strength of the concentric ornament giving a typical small-scale "spiders web" effect over nearly all the shell. The general outline of the shell is rather like the eared *K. lacunata* Öpik, but in that form the ribs are much coarser and are less numerous. The muscle impressions are considerably stronger than in *K. intacta*, and are reminiscent of those of *K. panderi* Öpik, but it differs from that form in its lower width/length ratio, and in the greater convexity of the dorsal valve. The ribs are finer and the concentric ornament is more evident. (Comparison was made with a British Museum specimen of *K. panderi* (BB 5182)).

LEPTESTIA Bekker.

Leptestia jukesi (Davidson).

PL. 6. FIGS. 1–3.

Strophomena jukesi Davidson 1869, p. 296, pl. xxxvii, figs. 23–26.

Leptestia musculosa Harper 1949, p. 56, footnote.

This species was based by Davidson on three syntypes, two of them internal moulds of the ventral, and one the exterior of a ventral valve. The author has collected from the original locality an internal mould showing both dorsal and ventral valves. Öpik (1930, p. 125) drew attention to the close similarity between this Irish fossil and *Leptestia musculosa* Bekker from the Kuckers of Esthonia, and pointed out that there were no certain differences between them, as far as could be ascertained without reference to the original Irish specimens. The author has compared the Irish material with an example of an Esthonian form in the British Museum collection

(B.M./BB 5188), and the similarities are indeed great. There are however a few distinctions which are important enough to enable it to be said that the two forms are not conspecific. *Leptestia jukesi* shows the following points of difference from *L. musculosa* Bekker :—(1) The hinge is straighter in the ventral valve ; (2) There is a conspicuous orthocline area in the ventral valve ; (3) The crura are further apart ; (4) Externally, the valves have a strong general curvature and are not geniculate as is usual in the Esthonian form (some of the Esthonian forms show no geniculation Öpik 1930, p. 127, fig. 77) ; (5) Externally the ventral valve is not so convex. In the ventral valve the muscle impressions are similar and the impressions of the spiral arms with their containing ridges look alike in both species. The median septum is longitudinally striated, the striations breaking up into little scales anteriorly (compare Öpik 1930, p. 127). In the dorsal valve also the muscle arrangement is similar in the two forms. Laterally there are branched vascular ridges at the hinge, passing anteriorly into radial striae (compare Öpik, *op. cit.*, p. 128). The rim of the disc is not preserved in the Irish specimen. The external ornament of the shell of *L. jukesi* is similar to that of *L. musculosa*, and shows very fine ribs with about six finer rays between, with rows of fine pits arranged longitudinally between the finer rays as described by Bekker for *L. musculosa* (1922, p. 364).

Material.

Lectotype (here chosen), G.S.I./J.C.H. 4944. The original of Davidson 1871, pl. xxxvii, fig. 24. Internal mould of ventral valve.

Paratypes. G.S.I./J.C.H. 2. Probably the original of Davidson, pl. xxxvii, fig. 23. Exterior of ventral valve. G.S.I./J.C.H. 4901. The original of Davidson 1871, pl. xxxvii, fig. 25. Internal mould of ventral valve.

Additional material. N.M.I./1951/7. Internal mould of ventral and dorsal valves. N.M.I./1951/8. Exterior of both valves.

Horizon. Grangegeeth Volcanic Series ; Upper Tuffs and Shales.

Locality. N.M.I. specimens from locality 3. G.S.I. specimens fron Survey Locality 1, Grangegeeth (=present locality 1 according to G.S.I. field maps).

Dimensions (in mm.)

	G.S.I./J.C.H. 4944 (Lectotype)	G.S.I./J.C.H. 4901 (Paratype)	N.M.I. 1951/8 (External ventral valve)
Hinge width ...	28.0	28.0	30.0 (est.)
Max width ...	31.0	30.0	33.5
Length ...	21.5	21.5	21.5

Remarks. Bekker's species is from the Kuckers C2 of Esthonia. The genus has not been recorded elsewhere from the British Isles, although Öpik (1930, p. 125), was aware of this Irish occurrence.

ÖPIKINA Salmon.

Öpikina celtica sp. nov.

PL. 5. FIG. 7.

PL. 6. FIGS. 10 AND 11.

Strophomena deltoidea Davidson, 1871, pl. xlii, figs. 3 and 4.

Material. Numerous specimens of this form are available, and the description is based on specimens in the Geological Survey of Ireland and National Museum of Ireland Collections.

Locality and Horizon. The Survey specimens presumably come from Survey Locality 1 (present loc. 1) or from the adjoining quarry which is the present Loc. 3, both of which are in the Upper Tuffs and Shales.

Holotype. Davidson figured three specimens from Grangegeeth which he referred to *S. deltoidea* ; one of these G.S.I./J.C.H. 4975 (the original of Davidson's fig. 3) is an internal mould of a dorsal valve and is here taken as the holotype of the new species.

Paratypes. G.S.I./J.C.H. 17 is an internal mould of a ventral valve and the original of Davidson's fig. 4.

N.M.I. 1951/14, 14a. Internal mould of both valves and external impression of dorsal valve.

Dorsal interior. Outline broadly U-shaped. Hinge straight with sharp cardinal angles not produced, about 90°. Area narrow, anacline. Visceral disc flat with sharp geniculation of 110°—115° at about 15 mm. from the hinge in mid-line, becoming sharper and nearly a right angle laterally. Sessile bifid cardinal process with a ridge between the two branches. Myophoric ridges at about 90° to one another, on either side of the cardinal process : curving anteriorly and dying out, becoming replaced by a tuberculate area which runs into a low ill-defined ridge bounding the disc. Median septum low near its origin at the cardinal process, becoming a sharp narrow ridge at about one-third the length of the disc ; then suddenly becoming low and ill-defined, terminating in a short sharp ridge which becomes a tubercle at about two-thirds of the way to the edge of the disc. A pair of short, low, ill-defined septa arises, one on each side of the median septum, between the myophoric ridges, running out at about 45° to the hinge and becoming sharp. At about 4 mm. from their origin they turn forwards at right-angles to the hinge and suddenly die out. Between these septa are a further pair of short septa which lie on either side of the median septum and parallel to it, turning sharply in towards it at their posterior end where the median septum is ill-defined. Anteriorly they run as far as does the median septum. A few faint radial marks are seen on ths anterior part of the disc. *Ventral interior.* Disc small in comparison with the whole valve. Diductor muscle impressions large, fan shaped, with median ridge ane extending two-thirds the length of the disc. Area narrow. Dental plates wed marked and diverging at about 95°. Adductors small and narrow, about one-thirll the length of the diductors. External ornament in both valves of fine radial threadd

with three or four fine striae in interspaces, crossed by extremely fine concentric striae; also a few faint concentric corrugations may be present.

Dimensions (in mm.) :—

	Hinge Width	Distance of Geniculation from hinge	Geniculation (laterally to median position)
G.S.I./J.C.H. 4975	22	15	105°
G.S.I./J.C.H. 17 ...	21	12	115°
N.M.I. 1951/14a ...	26	15	115°

Remarks. This form resembles *Ŏ. dorsata* (Bekker) which occurs in the Kuckers of Esthonia, especially in the arrangement and strength of the septa. The geniculation is less sharp externally in the Esthonian form, the septa are longer relative to the disc, and reach almost to its margin. The cardinal process is not so prominent in the Irish form.

Rafinesquina (*Playfairia*) *deltoidea var. multicorrugata* Reed from the Balclatchie Beds of Girvan is very close to *Ŏ. celtica* but has marked concentric corrugations. Salmon (1942, p. 571) has pointed out that *Playfairia* is a synonym of *Rafinesquina*. Reed's species is obviously an *Ŏpikina* and should be referred to as *Ŏpikina multicorrugata* (Reed).

Ŏpikina bailyi sp. nov.

Pl. 6. Fig. 12–14.

Holotype. G.S.I./J.C.H. 4998. An internal mould of a dorsal valve.

Paratypes. G.S.I./J.C.H. 4880. An internal mould of a ventral valve.

N.M.I. 1951/15, 15a external impression and internal mould of a dorsal valve.

Anterior outline of the shell less broadly rounded than in *Ŏ. celtica*; small ears may be present, tending to give shell a somewhat triangular outline. Distance from the hinge to point of geniculation about 15 mm.; angle of geniculation about 125°. External ornament as in *Ŏ. celtica*. *Dorsal interior* with bifid cardinal process; myophoric ridges are broad and low, rapidly dying out laterally. Broad median septum low posteriorly, almost dying out anteriorly, and then replaced by a sharp thread-like septum terminating half-way to the anterior edge of the disc. Two short broad septa rising to crests originate between the myophoric ridges one on each side of the median septum. A further pair of moderately sharp ridges runs between these septa and the median septum, parallel to the latter. *Ventral interior*—muscle impressions smaller than in *Ŏ. celtica* and do not extend beyond half the length of the disc. *Ŏ. bailyi* is found at Locs. 1 and 2.

Dimensions (in mm.) :—

	Hinge Width	Distance of geniculation from hinge	Geniculation
G.S.I./J.C.H. 4998 ...	20	14	125
G.S.I./J.C.H. 4880 ...	19	13	125
N.M.I. 1951/15a (est.)	20	c.13	—

Remarks. This species is distinguished from *Ö. celtica* by the more triangular outline of the shell and less sharp geniculation. In the interior of the dorsal valve the septa are very much less pronounced, and in the ventral valve the muscle impressions are considerably smaller.

Öpikina girvanensis (Reed).

PL. 6. FIG. 9.

Strophomena deltoidea Davidson 1883, pl. xv, fig. 16–22.
Rafinesquina (*Playfairia*) *deltoidea* Reed 1917, p. 866, pl. xi, fig. 21–30.
Playfairia girvanensis Reed 1945, p. 311.

One mould of a ventral valve (G.S.I./J.C.H. 2112) closely resembles some of those figured by Reed from Girvan. The valve has a disc with fine scaly tuberculation, and the muscle impressions are divided by a sharp narrow median septum. The dental plates diverge at about 120°. The valve is moderately geniculated and shows a few radial vascular markings beyond the geniculation. The resemblance is close to Reed's pl. xi, fig. 24, but near the margin are a number of radial grooves which are not shown in Reed's figure. The dorsal valve figured by Reed pl. xi, fig. 27, as belonging to the same species indicates that the form should be referred to *Öpikina*, Reed's name *Playfairia* being a synonym of *Rafinesquina* (Salmon, 1942, p. 571). The Irish specimen is from G.S.I. loc. 1.
Öpikina girvanensis is known from the Balclatchie Beds of Girvan.

ACIDASPIS Murchison.

Acidaspis (*Onchaspis*) cf. *lalage* Wyville Thomson.

PL. 5. FIG. 4.

Material. One small cranidium in the form of an external impression is available (N.M.I. 1951/13).

Horizon and Locality. The Upper Tuffs and Shales of Loc. 26.

Description. This form shows many of the characteristics of *A. lalage* Wyville Thomson. In the glabella the side lobes are completely cut off; the median lobe is slightly wider than the side lobes, but narrows rather more sharply anteriorly than in *A. lalage*; there is however some compression. The anterior end of the median lobe is expanded into low lateral projections. The front margin and the occipital lobes are not preserved. There is an indistinct occipital furrow. A median tubercle is placed between the posterior lateral lobes. Two long divergent spines, curving in slightly posteriorly project back from the occipital ring. Axial furrows deep, fixed cheeks swollen. Ornament of smaller and larger tubercles. Extreme posterior part of occipital ring where spines originate not ornamented. The spines bear a few large tubercles.

Remarks. A. lalage occurs in the Balclatchie Beds. The Irish form has a narrower median glabellar lobe and does not show any surface reticulation.

Cybele Lovén.

Cybele (*Cybelella*) cf. *rex* (Nieszkowski).

Pl. 5. Fig. 1.

Material. The material consists of an internal mould of a complete cephalon and a partly disarticulated thorax (G.S.I./J.C.H./1) and two fragmentary cranidia, N.M.I. 1951/11 and 11a, L.U. 7001.

Horizon. Grangegeeth Volcanic Series. Upper Tuffs and Shales.

Locality. G.S.I. Loc. 1 and J.C.H. Loc. 3. Grangegeeth.

Dimensions. G.S.I./J.C.H. 1 :—

Length of cephalon excluding frontal spines	12.0 mm.
Width of cephalon along posterior margin	35.5 mm.
Length of glabella (including occipital ring)	9.5 mm.
Width of glabella anteriorly excluding tuberculate lateral prolongations	9.0 mm.
Basal width of glabella	7.0 mm.

Cephalon short and wide with cheeks strongly bent down anteriorly and laterally Glabella moderately convex and more or less parallel-sided throughout most of its length, swelling at the frontal lobe, which also has anterior lateral prolongations reaching almost to the front margin of the cephalon. These projections each bear one tubercle and are cut off by a marked furrow, at the posterior end of which lies the deep antennary pit. The anterior end of the glabella is broadly rounded. On G.S.I./J.C.H. 1 the anterior margin carries at least 9 sharp tooth-like spines, which grade off laterally into tubercles, but only 6 or 7 are seen on the other specimens. There are coarse scattered tubercles on the glabella, a few of which are rather larger than the others and tend to form a double row in a median position. The lateral borders of the cephalon are tuberculate. Four pairs of glabellar furrows are seen, which take the form of deep pits with only a shallow furrow connecting them to the axial furrows. Cheeks swollen, free cheeks plunging steeply down. Ornament of pitting on cheeks with a few scatttered tubercles. Eyes at highest point of cheeks about half the distance between axial furrows and margin, opposite the first pair of glabellar furrows. Connected by eye lines to frontal lobe. Deep posterior furrow to head shield.

Thorax shows six or seven pleurae, the five anterior ones with rounded terminations the, posterior ones being strongly curved back and having pointed ends.

Remarks. Although this form has many resemblances to *Cybele* (*Cybelella*) *rex* Nieszkowski, the latter does not appear to have as many spines on the frontal margin as the Irish form. The length of the head is about one-third the breadth, a ratio which is not as great in *C. rex*. Schmidt (1881, p. 210), gives 11 : 25 and 10 : 21 for the Baltic form. The form and ornament of the glabella and cheeks, the position of the eyes and the course of the eye lines all suggest a close relation between the two forms. The type of *C. rex* comes from the Kuckers, C2, of Esthonia.

ILLAENUS Dalman.

Illaenus richardsoni, Reed.

PL. 5. FIG. 6.

Illaenus richardsoni. Reed 1914, p. 25, pl. iv, figs. 4, 5.

Material. Moulds of cranidia in collection of G.S.I., also N.M.I. 1951/17, 17a ; L.U. 7003.

Locality and Horizon. Locs. 1 and 3. Grangegeeth volcanic series. Upper Tuffs and Shales.

Remarks. The material agrees with Reed's description showing the short broad glabella, eyes set far back and the small median tubercle. The front of the glabella is truncate, and in L.U. 7003 can be seen to be sharply bent down anteriorly.

N.M.I. 1951/17, here figured, shows the free cheeks which are truncate in front. The neck furrow is more clearly defined than appears in Reed's figures. The facial sutures turn in slightly at their anterior end.

Dimensions (in mm.) :—

	Reed *loc. cit.*	N.M.I. 1951/17	L.U. 7003
Length of glabella	7.2	6.0	5.5
Length of preglabellar portion	18.8	13.0	11.0
Width of glabella at base	14.0	12.5	10.5
Width of cranidium across eyelobes ...	21.0	20.0 (est.)	16.0
Width of cranidium at front end ...	17.0	16.0	12.0

PROETUS Steininger.

Proetus ardmillanensis Begg.

PL. 5. FIG. 3.

Proetus ardmillanensis, Begg, 1947, p. 42, pl. iii, fig. 3.

Material. Mould of cranidia ; N.M.I. 1951/12, L.U. 7003, 7004, 7005, 7005a.

Locality and Horizon. Loc. 26, Grangegeeth Volcanic Series, Upper Tuffs and Shales.

Dimensions (N.M.I. 1951/12) :—

Length of cephalon ...	... 4.0 mm.
Glabella+occipital ring ...	... 3.0 mm.
Glabella (basal width) ...	... 2.0 mm.

This material agrees very closely with *Proetus ardmillanensis* Begg, the only slight difference being that the anterior rim turns up rather more sharply in the Irish form. There is no indication of the basal lobes which Begg (1947, p. 42) states are visible on the right (actually seen on the left, as shown in his figure) of his holotype (H.M. A3692). It is possible that this faint furrow is an accidental or occasional feature, as it is not seen in a topotype specimen H.M. A3825. Neither is the median neck tubercle visible in this latter specimen, and it is also absent in the Irish material.

Remarks. Begg's specimens come from the Balclatchie Beds of Dow Hill, Girvan. The species resembles in size and general appearance *P. zalesskyi* Öpik (1928, p. 33), in which however three faint glabellar furrows are seen, bringing the form very close to *P. vetulus* Reed, from the Balclatchie Beds. It should be noticed that Öpik figures a specimen of *P. zalesskyi* in which these three furrows appear to be absent (Öpik 1937, pl. iii, fig. 3), giving the form practically specific identity with *P. ardmillanensis*. *P. zalesskyi* is from the Kuckers, C2, of Esthonia.

Pseudobasilicus Reed.

Pseudobasilicus sp.

Pl. 5. Fig. 2.

Asaphus radiatus, Salter 1866b, pl. xviii, figs. 4 and 5.

The material available consists of moulds of pygidia from Collon, Co. Louth, G.S.M. 12836, 12837, 12840. The lithology of these specimens suggests that they come from Loc. 8 of the Irish Survey Memoir, although no mention of the species is made in the faunal lists from there (Hull, Cruise, and Baily, 1871, p. 16). Other specimens have been collected by the present author from nearby localities in the same type of rock, viz., locs. 30 and 44. The horizon is probably that of the Upper Tuffs and Shales of the Grangegeeth Volcanic Series. Fragments of asaphid pygidia, which may belong to the same species, were found at Loc. 26, which is definitely in the Upper Tuffs and Shales.

The pygidium is nearly semicircular and more than twice as wide as long, although the specimens are probably somewhat widened by distortion. Axis narrow, about three-quarters the length of the pygidium, narrowing gently posteriorly, and with a rounded termination. Axial rings probably about twelve in number, the posterior ones being too poorly preserved to allow an accurate count. Side lobes seven, with a possible trace of an eighth posteriorly, dying out about three quarters of the way to the border. Anterior lobes inclined gently backwards, the posterior ones rather more sharply. Doublure markings well shown, extending anteriorly about half way from the lateral border to the axis and passing posteriorly close to the termination of the axis.

Dimensions. G.S.M. 12387 and 12840 (counterparts)—Figd. Salter 1866b, pl. xviii, fig. 4.

Width of pygidium anteriorly	...	...	75 mm.
Length of pygidium	...	...	32 mm. (estimated).
Width of axis anteriorly	...	...	14 mm.
Length of axis	...	...	23 mm.

Remarks. This form cannot be referred to *Pseudobasilicus radiatus* (Salter); the latter species as originally figured by Salter (1866a, pl. xxiii, fig. 7), was shown as having the pygidial axis with a longitudinal ornament, a feature which is also shown in Salter's later figure (1866b, pl. xviii, fig. 3). Certain pygidia found by the author in the Ashgillian *Phillipsinella parabola* beds near Llanystwmdwy, Criccieth, which resemble the Irish pygidia closely, are associated with forked hypo-

stomes and would appear to be referable to Reed's genus *Pseudobasilicus*. Reed (1931, p. 465) referred *A. radiatus* to Novak's genus *Ptychocheilus* which has as its type species *Ogygia discreta* Barrande. The characters of the Collon specimens and all those pygidia figured by Salter as *A. radiatus* (1866b, pl. xviii, figs. 1–5) are more closely allied to the group including *Basilicus lawrowi* (Schmidt), the type species *A. nobilis* Barrande, *Basilicus kuckersianus* (Schmidt), and *B. kegelensis* (Schmidt) all of which Reed originally included in *Pseudobasilicus* (Reed, 1930, p. 308). It should be noted that Reed (1931, p. 465) in referring Salter's original figure of *A. radiatus* to *Ptychocheilus* states the original to be G.S.M. 12836. The latter number belongs to a Collon specimen which Salter did not figure in his later work (1866b, pl. xviii). It seems probable that Salter's figure (1866a, pl. xviii, fig. 7) was based on a distorted specimen, G.S.M. 12833 (which should therefore be regarded as the lectotype of *A. radiatus*) from the Ashgill of Cerrig-y-druidion, North Wales. This specimen is the original of Salter 1866b, pl. xviii, fig. 3.

It is of interest that two large pygidia, which are not dissimilar in number of axial rings and side lobes from the Collon *Pseudobasilicus*, were found in drift near Pomeroy (Nolan and Baily, 1878, p. 24). These are at present in the collections of the British Geological Survey, and are temporarily numbered T.N. 1715, 1716. The associated rock does not resemble any of the Ordovician beds known at Pomeroy.

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EXPLANATION OF PLATES.

PLATE 5.

1. *Cybele* (*Cybelella*) cf. *rex* (Nieszkowski) GSI/JCH 1.
   Locality 1. Cephalon and part of thorax. x 3/2 (p. 106).
2. *Pseudobasilicus* sp. GSM 12840.
   Locality 246. Pygidium. x 3/4 (p. 108).
3. *Proetus ardmillanensis* Begg. NMI 1951/12.
   Locality 26. Cranidium. x 11/4 (p. 107).
4. *Acidaspis* (*Onchaspis*) cf. *lalage* Wyville. Thomson. NMI 1951/13.
   Locality 26. External impression of cranidium. (Light from bottom right hand corner). x 5/2 (p. 105).
5. "*Phacops*" cf. *kuckersianus*. F. Schmidt. GSI/JCH 529.
   Locality 1. Cephalon. x 3/2 (p. 88).
6. *Illaenus richardsoni* Reed. NMI 1951/17.
   Locality 1. Cephalon. x 3/2 (p. 107).
7. *Ōpikina celtica* sp. nov. NMI 1951/140.
   Locality 1. External impression of dorsal valve. x 3/2 (p. 103).
8. *Hesperorthis inostrantzefi* (Wysogorski). NMI 1951/10a.
   Locality 1. Internal mould of ventral valve. x 3/2 (p. 100).
9. *Hesperorthis inostrantzefi* (Wysogorski). NMI 1951/10.
   Locality 1. External impression of dorsal valve and area of ventral valve. (Light from bottom right hand corner). x 3/2 (p. 100).
10. *Hesperorthis inostrantzefi* (Wysogorski). NMI 1951/9.
    Locality 1. Internal mould of dorsal valve. x 3/2 (p. 100).

PLATE 6.

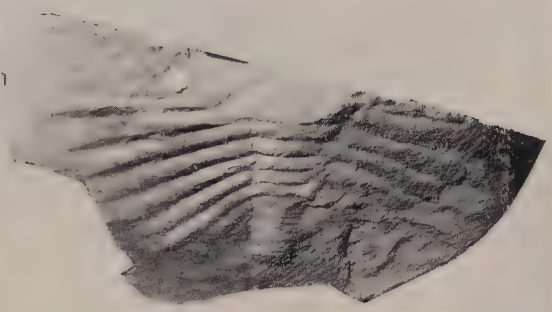
1. *Leptestia jukesi* (Davidson). Paratype. GSI/JCH 4901.
   Locality 1. Internal mould of ventral valve. x 3/2 (p. 101).
2. *Leptestia jukesi* (Davidson) Lectotype. GSI/JCH 4944.
   Locality 1. Internal mould of ventral valve with part of shell adhering. x 5/4 (p. 101).
3. *Leptestia jukesi* (Davidson). NMI 1951/7.
   Locality 3. Internal mould showing dorsal valve. x 3/2 (p. 101).
4. *Actinonema subarachnoidea* (Reed). GSI/JCH 6.
   Locality 1. Exterior. Ventral valve. x 7/4 (p. 98).
5. *Actinonema subarachinodea* (Reed). NMI 1951/16.
   Locality 3. Internal mould of ventral valve. x 5/4 (p. 98).
6. *Kullervo hibernica* sp. nov. Paratype. NMI 1951/18.
   Locality 23. External impression of dorsal valve (light from bottom right hand corner). x 13/4 (p. 100).

7. *Kullervo hibernica* sp. nov. Holotype. NMI 1951/18a.
Locality 23. Internal mould of dorsal valve. x 3/2 (p. 100).
8. *Kullervo hibernica* sp. nov. ? GSI/JCH 2089.
Locality 1. Internal mould of ventral valve. x 3 (p. 100).
9. *Õpikina girvanensis* (Reed). GSI/JCH 2112.
Locality 1. Internal mould of ventral valve. x 5/4 (p. 105).
10. *Õpikina celtica* sp. nov. Paratype. GSI/JCH 17.
Locality 1. Internal mould of ventral valve. x 5/4 (p. 103).
11. *Õpikina celtica* sp. nov. Holotype. GSI/JCH 4975.
Locality 1. Internal mould of dorsal valve. x 5/4 (p. 103).
12. *Õpikina bailyi* sp. nov. Holotype. GSI/JCH 4998.
Locality 1. Internal mould of dorsal valve. x 3/2 (p. 104).
13. *Õpikina bailyi* sp. nov. Paratype. GSI/JCH 4880.
Locality 1. Internal mould of ventral valve. x 5/4 (p. 104).
14. *Õpikina bailyi* sp. nov. Paratype. NMI 1951/15.
Locality 1. External impression of dorsal valve. x 3/2 (p. 104).
15. *Catazyga anglica* (Davidson). GSI/JCH 4.
Locality 1. Internal mould of ventral valve. x 7/4 (p. 98).
16. *Catazyga anglica* (Davidson). Lectotype. GSI/JCH 3.
Locality 1. Internal mould of dorsal valve. x 7/4 (p. 98).
17. *Catazyga anglica* (Davidson). GSI/JCH 2136.
Locality 1. Internal mould of ventral valve. x 3/2 (p. 98).
18. *Catazyga anglica* (Davidson). GSI/JCH 5.
Locality 1. Internal mould of dorsal valve. x 2 (p. 98).

Plate 7.

Geological Map of the District.

1 x 3/2



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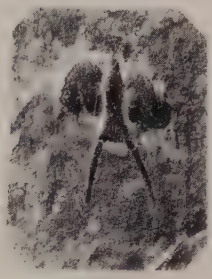
3 x 1 1/4



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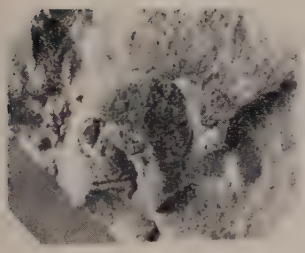

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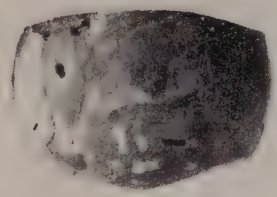

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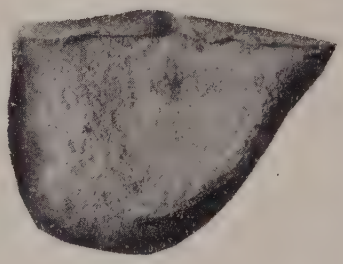

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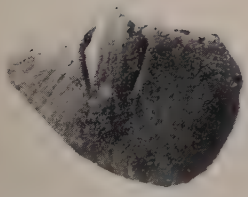

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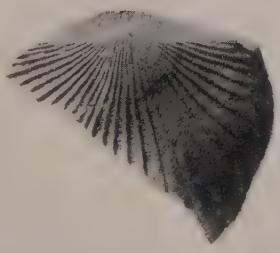

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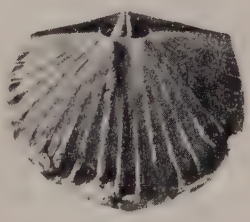

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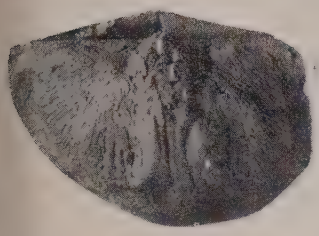

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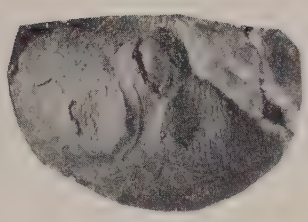

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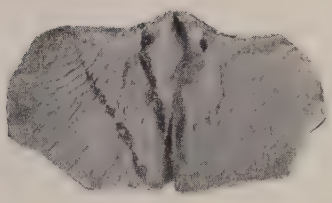

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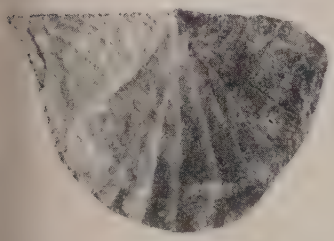

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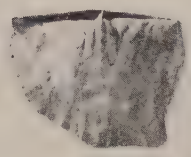
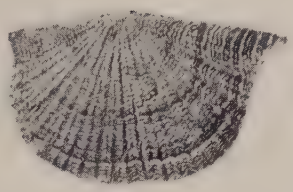


5 x 5/4



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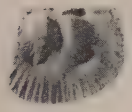

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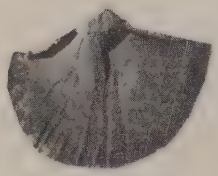

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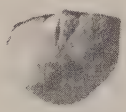

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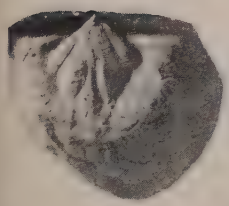

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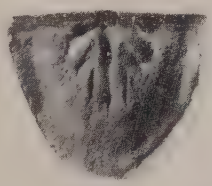

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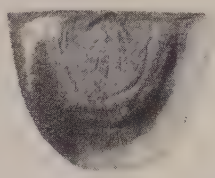

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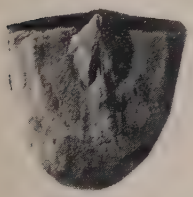

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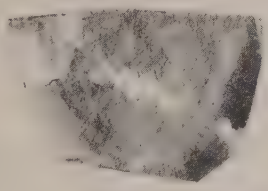

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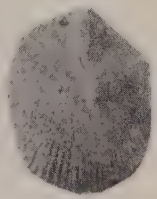

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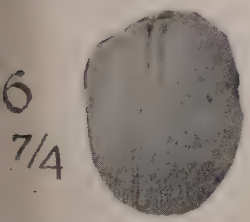
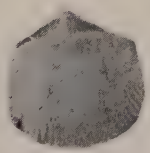


16 7/4



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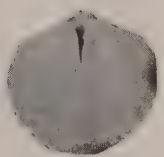

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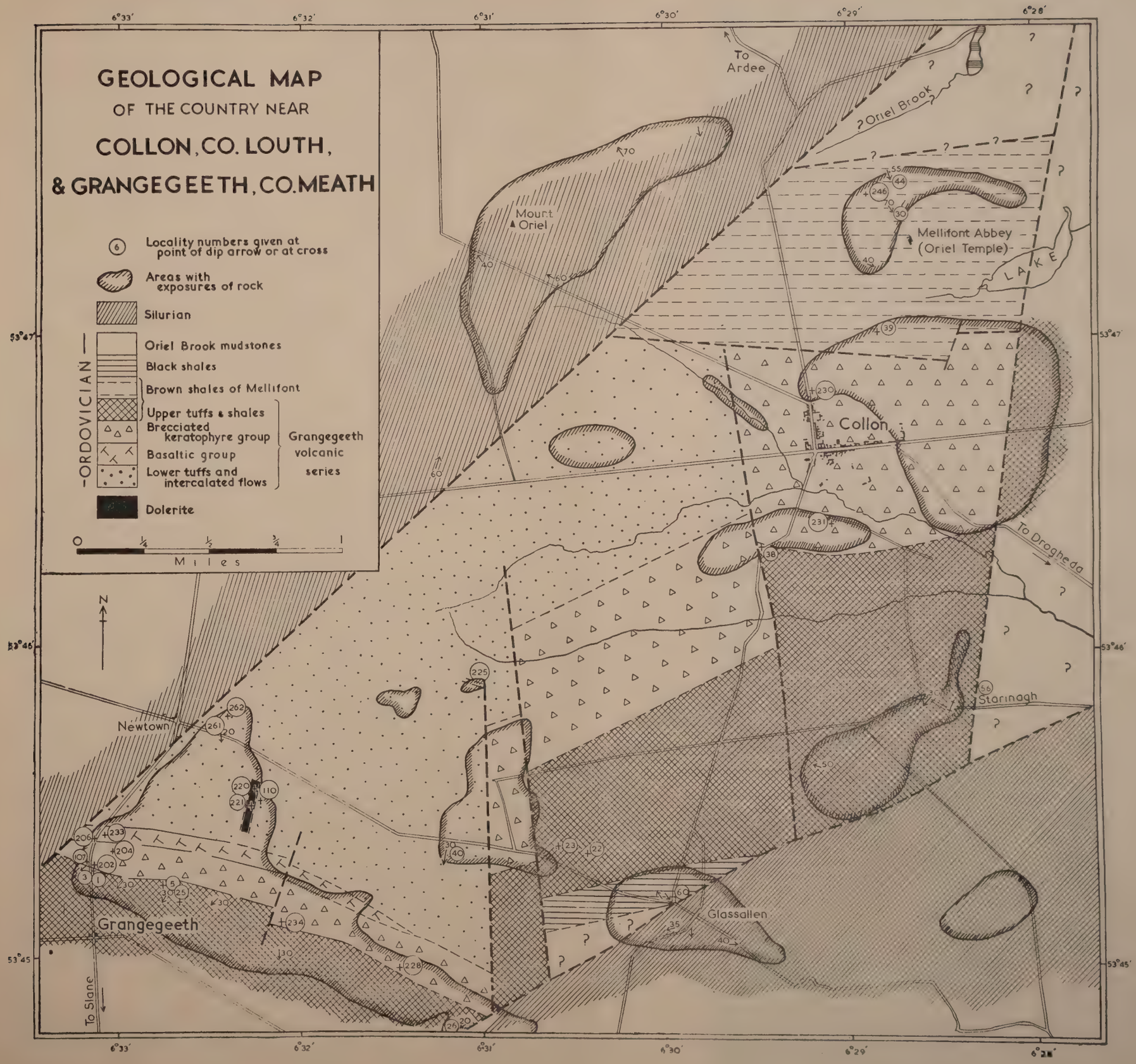
GEOLOGICAL MAP
OF THE COUNTRY NEAR
COLLON, CO. LOUTH,
& GRANGEGEETH, CO. MEATH
6 Locality numbers given at point of dip arrow or at cross
Areas with exposures of rock
Silurian
ORDOVICIAN
Oriel Brook mudstones
Black shales
Brown shales of Mellifont
Upper tuffs & shales
Brecciated keratophyre group
Basaltic group
Lower tuffs and intercalated flows
Grangegeeth volcanic series
Dolerite
0 ¼ ½ ¾ 1
Miles
N
6°33′
6°32′
6°31′
6°30′
6°29′
6°28′
53°47′
53°46′
53°45′
To Ardee
?Oriel Brook
Mount Oriel
Mellifont Abbey (Oriel Temple)
LAKE
Collon
To Drogheda
Starinagh
Newtown
Grangegeeth
Glassallen
To Slane

No. 5

THE ORDOVICIAN VOLCANIC ROCKS BETWEEN COLLON (CO. LOUTH), AND GRANGEGEETH (CO. MEATH).

BY

B. E. MANISTRE, M.A., F.G.S.

[Read November 25, 1952. Published December 17, 1952]

(Communicated by the late Professor L. B. Smyth)

Plates 8 and 9

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I. Introduction.
II. Petrography.
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II(*b*) The basaltic group.
II(*c*) The keratophyric group.
II(*d*) The pyroclastic group.
III. Chemical features.
IV. Relationships with other Ordovician areas.

SUMMARY.

Some Ordovician volcanic rocks are described from an inlier thirty miles north of Dublin. The lavas are found at two principal horizons with pyroclastic rocks above and below them. A lower group of mugearitic basalts is characterised by euhedral pseudomorphs after olivine, fresh augite, and albitised felspar phenocrysts. These are overlain by a thick series of keratophyres which are generally autobrecciated to a high degree. Hornblende-bearing types predominate, but some augite keratophyres are also present. The felspars are highly sodic throughout. Chemical analyses of these types are discussed, and the importance of the ratio of soda to potash in the spilitic rocks is stressed. A diagram showing the trend of this ratio for a normal calc-alkali rock series in which secondary albitisation has been effected, suggests a divergence between this trend and that produced when a primary soda rich magma is differentiated. This may be of use in distinguishing cases of soda metasomatism where no textural evidence of replacement is left in the felspars. The chemical nature of the lavas is compared with the spilites and related rocks by means of the Niggli Q-L-M triangular diagram, which suggests that they are related genetically by a differentiation process involving the removal of ferro-magnesian constituents from the original magma. A brief comparison of the area with other volcanic occurrences of similar age is given.

I.—Introduction.

The igneous rocks described form part of a small inlier of Ordovician rocks which lies some thirty miles north of Dublin, and seven miles west of Drogheda. The area begins north of Slane on sheet 91 of the Geological Survey of Ireland's 1-inch series maps, and extends north-eastwards into the adjacent sheet 81.

In the explanatory memoir of 1871, Edward Hull and R. J. Cruise described the component rocks as dark grey and green shales and slates of Bala age, variously interstratified with felstones and felspathic ashes. Hull recognised the igneous rocks as contemporaneous, possessing a general E.N.E.—W.S.W. strike, corresponding to that of the sediments, and a south-easterly dip. In the absence of definite evidence it was suggested that the original vents lay concealed by the Carboniferous rocks to the south. A revision of the whole area was completed by F. W. Egan and A. McHenry (1896, p. 48) some twenty-five years later. Anticlinal inliers of lower Silurian rocks were recognised near Slane, and H. J. Seymour (1898, p. 63) catalogued the Survey collection of igneous rocks from the area as volcanic tuffs or breccias, altered andesites, dolerites, and basalts.

Before the revised maps were sent to the engraver, however, the igneous rocks were again examined, this time by McHenry (1899, p. 75), who arrived at an entirely different conclusion. He wrote, " The two long East-West masses of rock mapped as felstone at Grangegeeth, three miles north of Slane, are now determined not to be igneous at all, but merely an arkose, composed of broken up and disintegrated felspathic detritus in a fine green sandy matrix, which contains fossils in places." The latest edition of the revised map marks the area concerned as " Llandovery with conglomerate." The further examination of these rocks which has been undertaken leaves no doubt of their volcanic nature, and a return is made largely to the interpretations of Seymour, except that the chemical peculiarities and the nature of the felspars suggest the use of a different nomenclature.

Evidence of the age of the vulcanicity is confined to the nature of the fauna in the fossiliferous tuff overlying the keratophyric group. This indicates a Caradocian age for this horizon. The base of the volcanic series is not exposed, but the nature of the rocks is such that they probably accumulated rapidly. Further outcrops of volcanic rocks are known to occur south-west of the Grangegeeth–Collon area. These appear to be a further series of tuffs and lavas of broadly similar characteristics to the ones described in this paper.

II.—Petrography.

II(*a*) *The General Characteristics of the Suite.*

Lavas have been mapped at two main horizons in the inlier. They comprise a lower basaltic group, and an overlying intermediate series in which autobrecciated keratophyres greatly predominate. Pyroclastic rocks are found both above and below the two lava groups, in a mixed series which includes both coarse and fine tuffs, mudstones, and occasional isolated lava flows. The whole series has been called the Grangegeeth Volcanic series.

The keratophyres may be traced eastwards from the ridge which they form north of Grangegeeth cross roads. Their conspicuous brecciation affords the most readily mapped feature in the area. Striking E. to E.N.E. and with a general dip of some 30° S., the outcrops are displaced northwards by a series of dip faults. As each fault is crossed the width of the outcrop is found to be progressively greater on the downthrow side. Assuming a constant dip this implies that the keratophyres originally increased in thickness towards the north, presumably towards the centre of eruption.

The underlying basaltic lavas may be followed for a short distance only, as they soon disappear under drift, and are not exposed elsewhere. Their thickness is of the order of 100 feet, whilst that of the keratophyres varies from 300 feet at Grangegeeth to a possible 2,000 feet at Collon.

Mineralogically the basalts are characterised by euhedral augite, albitic felspar, and remarkably perfect pseudomorphs after olivine. These minerals occur as phenocrysts in a groundmass of felspar laths and alteration products. Porphyritic textures with flow alignment of the small felspar laths are always found. The keratophyres are distinguished by chloritic pseudomorphs after hornblende, albitic felspars, and a highly altered base of carbonate material and chlorite. Their textures are often brecciated, accompanied by a patchy distribution of flow structures, both features being commonly observed in the same slice. The pyroclastic rocks are largely composed of felspar fragments with interstitial chloritic material and iron ores.

The association with muddy sediments, and the fossiliferous nature of some of the tuffs, might suggest that the eruptions were submarine. Against this, however, there is a marked absence of pillow structures and evidence of the oxidation of the iron ores to hæmatite, particularly in the keratophyres. It seems more reasonable to suppose that one or more volcanoes were built up, and stood as islands in shallow water. In this way the rapid increase in thickness of the keratophyres is also most readily explained.

The numbers in brackets in the text refer to localities marked on the map. (Plate 7 of the previous paper.)

II(*b*) *The Basaltic Group.*

These lavas are best exposed near the Grangegeeth–Newtown road, in the stream west of the road, and in the lane leading to the farm on the east. They are very dark porphyritic rocks, mostly with prominent calcite-filled vesicles. The predominent phenocrysts are of black augite and vary in length up to about 5 mm.; their characteristic crystal form may be seen with the unaided eye (206). Smaller and less common phenocrysts of felspar, and pseudomorphs after olivine, may be distinguished with the aid of a hand lens. Exposures do not permit the following of particular flows for any great distance.

In thin sections the phenocrysts are seen to be euhedral and set in a groundmass of felspar laths with flow alignment, averaging 0.2 mm. in length. The augite crystals are colourless and often twinned, sections close to 010 giving an extinction angle of 42° (z : c). Alteration to chlorite is only incipient in unweathered specimens.

Features of the felspar phenocrysts include poorly defined lamellar twinning and slight variations in birefringence distributed in patches or with a rough attempt at zoning. In addition, each phenocryst has a narrow outer rim with a paler grey polarisation colour which extinguishes at a small angle to the main portion of the crystal. Determinations of the refractive index (always less than that of Canada Balsam) and optic sign (positive) show that the composition is albite. Some instances where the outer rim showed a higher refractive index than the main portion were found, suggesting that the composition of this part may approach oligoclase. In view of the chemical evidence discussed in Section III the felspars are considered to have been originally zoned plagioclases, in which the zones more basic than oligoclase have been replaced by albite.

The remaining phenocrysts are carbonate pseudomorphs after olivine. The prismatic and steep-sided pyramidal sections of this mineral are well preserved in many instances (see Plate 9, fig. 3). Staining and acid tests show that the carbonate is attacked immediately and is therefore not ankerite or dolomite.

Felspar laths with good flow alignment, interstitial chlorite, carbonate, and iron oxide, make up the groundmass. From the prevalence of straight extinction, and the closeness of their refractive indices to that of Canada Balsam, the composition of the laths is believed to be oligoclase. Magnetite is the usual iron oxide, but in one slice (233) haematite accompanies it, particularly associated with the carbonate pseudomorphs.

In their minerological characters, therefore, these lavas show affinities with the spilites, the principal difference being that they had originally about ten per cent. of olivine. They are less altered than typical spilites. Their groundmass of oligoclase laths is also similar to the mugearites, an alliance which is also supported by the chemical features given in Section III. The classification of the group is thus largely a matter of emphasis. If this is placed on their chemical composition they are perhaps closer to the mugearites than to the spilites.

Rocks of an essentially similar character are exposed at (220) and (221) on small mounds elongated approximately north-south. The principal distinction between these rocks and the basalts is a textural one. Although remaining porphyritic the texture may also be described as doleritic, the groundmass felspar laths averaging 0.5 mm. in length. An absence of vesicles adds to the belief that these exposures are part of a small dyke, although the field evidence is not conclusive. Euhedral augites are again prominent phenocrysts, and possess the same features as those in the basalts. The olivine pseudomorphs are scarcer here and attain only three or four per cent. of the rock. Their habit is now anhedral, with serpentine as the replacing material and not calcite. A few felspar phenocrysts are present with the same features as described above, and the groundmass laths are again oligoclase. A few flakes of biotite may be seen interstitally with chlorite, magnetite, haematite, and accessory apatite. The rock is thus a slightly more acid variant of the mugearite magma, and shows evidence of slower cooling, probably as a shallow intrusion. The chemical evidence of Section III suggests that the dyke comes between the basaltic group and the keratophyres in time. There is no field evidence

relative to the basaltic group, but it does not cut the main keratophyre ridge to the south.

II(*c*) *The Keratophyric Group.*

This group forms the most resistant part of the whole volcanic suite, and is also the most widely exposed. It includes the masses described by McHenry as " arkose " or " conglomerate " (1899, p. 75), and may be traced from the ridge north of Grangegeeth cross-roads (5) to the large quarry at Collon (231), where the greatest thickness is seen. In the field-exposures the rocks present a strongly brecciated appearance, a feature which tends to obscure their extrusive character. A study of specimens from different horizons within the group shows that it is to be regarded essentially as a series of autobrecciated lavas, predominantly hornblende keratophyres, but with some augite-bearing flows and thin bands of fine ash interspersed. The difficulties attendant on distinguishing autobrecciated lavas from some forms of purely fragmental breccia were pointed out by Mitchell in connection with the volcanic series of Kentmere (Mitchell, 1930, p. 4). These difficulties are also encountered in the Grangegeeth keratophyres, and some horizons may be more correctly described as agglomerates, particularly where the thickness is greatest.

All the Grangegeeth keratophyres are rocks of intermediate character, without primary quartz, and characterised by sodic felspars. They thus fall between the spilites and the soda trachytes, and have been named on this basis. The hornblende and augite-bearing types are considered separately.

II(*c.i*) *The Autobrecciated Hornblende Keratophyres.*

The appearance of these rocks in hand specimen is shown in Plate 8. Three component parts may be distinguished and are lettered in the photograph. They comprise :—

A. Reddish-coloured blocks mostly rounded but some angular, and up to about a foot in diameter. They consist of a fine-grained red base in which white felspar crystals are embedded in varying proportions.

B. Dark green but otherwise similar blocks.

C. A dark green matrix enclosing the blocks and comparatively free from large felspars, but with scattered red flecks.

In describing the Kentmere autobreccias Mitchell (*op. cit.*) envisages the formation of an outer skin or crust on the lava, which is broken and cemented by the still liquid central portion. The new heterogeneous crust may in its turn be broken and recemented, the process continuing until the whole of the liquid interior of the flow has solidified. The Grangegeeth keratophyres are also believed to have been formed by a mechanism of this kind. An essentially similar process was also envisaged by Benson in describing the keratophyres of the Hydes Creek complex (Benson, 1915).

In thin section the difference between components A and B is seen to rest on the degree of oxidation of the iron oxides, the boundaries of such blocks being difficult to locate until the use of reflected light reveals the portion in which the iron oxide is predominantly haematite. These components are regarded as parts of the flows

which solidified early as crustal portions, with oxidising conditions at the actual surface. During the subsequent slow movement of the flows these outer portions were broken, partly abraded and rounded, and recemented by the remaining liquid (component C). Flow alignment of small felspar laths is observed in some sections, sometimes oriented in more than one direction within the area of a single microscope slide. Component C also contains fragmental material derived from the breaking up of the crustal blocks, and where this predominates flow structures are absent. The texture may then become indistinguishable from that of a coarse tuff or agglomerate.

These features are well seen in specimens from (202). One slice shows a dominantly pyroclastic texture, and has been cut across the boundary between a red block and the green matrix (components A and C). Both euhedral and fractured felspar crystals form the bulk of the rock. They are accompanied by pseudomorphs after hornblende in subordinate amount, both minerals lying in a base of chlorite, carbonate, and iron oxide. These pseudomorphs are brownish in ordinary light, and range up to 2 mm. in length. They are now composed of an intimate mixture of chlorite and iron oxide dust. Some of the pseudomorphs which have a more lath-like habit may be after biotite. The accompanying felspars are predominantly fresh plagioclase, with albite and pericline twinning, up to 4 mm. in length. A number of sections oriented perpendicular to (001) and (010) by means of the universal stage, gave extinction angles of 11°—12° corresponding to a composition of An_{6-7}. A small proportion of potash felspar is also present, showing simple Carlsbad twinning, and with a negative sign. The iron oxides may be separated by reflected light into black octahedra of magnetite, occasional small aggregates of twinned ilmenite laths, and flakes of haematite. The latter is also present as a dispersed dust imparting a reddish cast to the groundmass of component A.

Another slice from this locality has been cut from component B, and again shows the euhedral felspars and hornblende pseudomorphs set in a chloritic base. In this instance minute felspar laths are present in parts of the groundmass with flow orientation. The association of these flow structures with fractured felspars is interpreted as a feature of the autobrecciation.

The same features are observed in specimens from (5). Here, at the top of the series, fossils are found embedded in keratophyre debris. Specimens from the thickest part of the group at (230) and (231) show no new mineralogical features. Partial later silicification is sometimes observed, and a spherulitic grouping of felspar laths is seen, as shown in Plate 9, fig. 5. Some of the hornblende pseudomorphs have strong reaction rims, now haematite, surrounding a chloritic centre (Plate 9, fig. 6). In one slice (230) small fragments of the original hornblende are preserved. They are pleochroic from brownish green to pale green with deep reaction borders. Pseudomorphs after biotite may be distinguished by outline and cleavage cracks picked out in iron oxide.

At least two carbonates can be shown to be present in some of the keratophyres. This is particularly evident when the hornblende pseudomorphs are of carbonate material. Treatment with cold dilute hydrochloric acid dissolves the central portions of the pseudomorphs leaving a narrow marginal border of carbonate material un-

affected. The two carbonates are normally in optical continuity but show a difference of refractive index, the composition of the outer border being probably either ankerite or dolomite. This evidence suggests strongly that the original hornblende was replaced first by an iron-magnesian-bearing carbonate derived partly from its own elements, the latter being itself replaced by calcite at a later date.

II (*c. ii*) *The Non-brecciated Hornblende Keratophyres.*

An example of a less brecciated flow comes from (204). Here the texture is that of a normal lava flow, a consistent alignment of the felspar phenocrysts being visible in the hand specimen. Under the microscope the felspar phenocrysts predominate, showing the same features of birefringence and zoning described in Section II(b). They are less fractured than in the brecciated flows, and show a higher degree of sericitisation. The hornblendes are again replaced by chlorite, and have ill defined crystal boundaries. The groundmass consists of small stumpy felspar prisms with interstitial chlorite, iron oxides, and apatite. Patches with higher birefringence are intimately associated with the chlorite, and are interpreted as finely divided sericite or epidote.

II(*c. iii*). *The Augite Keratophyres.*

These have been found at (228) and (234). A specimen from the first locality shows phencrysts of black augite and highly altered felspar in a green matrix with occasional red staining. This appearance is conspicously different from that of the hornblende keratophyres which are speckled white with unaltered felspar. The (234) rock has both augite and felspar visible in hand specimens. The augite is fresh and euhedral, and is accompanied by a few pseudomorphs after hornblende in green chlorite and calcite. In the rock from (228) the felspars are highly sericitised, but otherwise similar to those previously described. The groundmass is here a mixture of chloritic alteration products and iron oxides with some haematite staining.

The other augite-bearing keratophre (234) is similar but of coarser texture. The principal difference lies in the presence of sphene in association with the hornblende pseudomorphs. This is the only occurrence of this mineral in the area. It appears as rows of dark brown granules, both rounded and wedge-shaped, sometimes related to previous cleavage directions in the hornblende. Clumps of magnetite grains are also associated with the pseudomorphs. The groundmass follows the same pattern as in (228).

II(*d*) *The Pyroclastic Deposits.*

The purely fragmental deposits above and below the two series just described vary a good deal in coarseness and character. Typically they are crystal tuffs, accumulations of felspar fragments set in a base of alteration products, without shard forms or lava fragments. The incompleteness of the exposures does not allow a complete sequence to be given, but there seems to be a general tendency for the tuffaceous deposits above the keratophyres to become finer and grade off into mudstones. At least two isolated lava flows have been found in the tuffs at (225) and (246), and it seems likely that others are present but not exposed. The upper and lower tuffs are considered separately.

II (*d. i*) *The Lower Group.*

A small quarry at (261) shows a coarse ash band containing conspicuous fragments of dark grey, poorly bedded, mudstone up to one inch in length. The bulk of the deposit is felspathic with limonitic patches. Below this again at (262) a limonitic mudstone occurs with patches and sinuous layers of felspar fragments. The felspar occurs in small rectangular prisms, fresh, but rarely twinned. With refractive indices less than Canada Balsam, they appear to be of albitic composition, but some potash felspar may be present as well. A pale-coloured fine tuff from (110) is highly felspathic with a few scattered pseudomorphs in chlorite, and a little fresh biotite. The leucocratic nature of these tuffs suggests that the magma responsible may have been appreciably more acid than the keratophyres, but no flows have been found in the vicinity.

The lava from (225) is a typical non-brecciated hornblende keratophyre, showing great similarity both mineralogically and texturally with the example described from (204). The extent of this flow is not known owing to the scarcity of exposures.

II (*d. ii*) *The Upper Group.*

The deposits overlying the keratophyres grade upwards into fine-bedded ashes and mudstones. The fossiliferous locality (3) yields a medium grade tuff with abundant fresh felspar crystals set in a chloritic base. Typical shard forms are never seen, but some of the alteration products may be the result of devitrification. A number of rock fragments up to an inch and a half long have been found in this tuff. They are angular to sub-angular and show white felspar phenocrysts in a dark glassy matrix. Their appearance suggests that they are fragments of keratophyre, either eroded from portions of the volcano, or the result of a violent explosion.

It is considered on palæontological grounds that the brown shales of Mellifont may be the same age as the upper tuffs. The lava from (246) may thus be the youngest flow in the area. It is again a hornblende keratophyre closely similar to those from (204) and (225).

III.—Chemical Features.

It was pointed out in section II(b) that the basaltic group possesses mineralogical features which ally it on the one hand to the spilites, and on the other to the mugearites. Chemical analyses of specimens from (206) and (220) are given in Table I, accompanied for comparison by analyses of the average spilite as given by Wells (1923, p. 69), and a mugearite from the Skomer island volcanic series (Thomas, 1911, p. 202). The alkali percentages indicate a sodic tendency in the basalts but it is less strongly marked than in the average spilite. Moreover, it has been established that one of the chemical features characteristic of the spilites is a considerably lower potash content than has been found at Grangegeeth (Gilluly 1935, p. 249). As compared with the Skomer mugearite the analyses show higher magnesia and lower iron percentages. These differences are also the distinction noted by Thomas between the mugearites and his specially created type, the marloesite (1911, p. 200). It is to this latter type that the Grangegeeth basalts appear to be closest in their chemical composition, and an analysis of a marloesite is therefore also included in Table I.

Table 1.

	I	II	III	IV	V	VI	VII
SiO_2 ...	44.26	48.67	46.01	50.19	49.80	55.42	55.38
Tio_2 ...	1.63	2.03	2.21	2.72	1.73	0.41	0.90
Al_2O_3 ...	14.13	16.70	15.21	14.57	16.24	17.48	18.34
Fe_2O_3 ...	3.16	4.21	1.35	4.39	3.85	0.65	1.13
FeO ...	5.21	4.69	8.69	8.96	5.31	3.47	5.86
MnO ...	—	—	—	0.32	0.27	—	—
MgO ...	7.52	4.67	4.18	2.79	4.52	4.30	3.47
CaO ...	11.95	8.24	8.64	7.60	4.03	4.78	3.25
Na_2O ...	3.44	3.99	4.97	4.24	4.88	5.49	7.12
K_2O ...	1.36	1.68	0.34	1.53	2.51	1.74	0.22
H_2O+ ...	2.91	3.34	2.48	1.54	2.43	1.84	2.39
H_2O- ...	0.17	0.14	—	0.32	1.08	0.14	0.48
P_2O_5 ...	0.42	0.40	—	1.12	0.18	0.21	tr.
CO_2 ...	4.21	1.28	4.98	0.02	3.22	4.18	2.00
	100.37	100.04	100.00	100.30	100.07	100.11	100.54

I. Mugearite. Grangegeeth (206). Anal. B. E. Manistre.
II. Doleritic intrusive. Grangegeeth (220). Anal. B. E. Manistre.
III. Average of seven spilites. A. K. Wells (1923), p. 69.
IV. Mugearite. Skomer island. H. H. Thomas (1911), p. 202. Anal. E. G. Radley.
V. Marloesite. Marloes, Pembroke. N. H. Thomas (1911), p. 200. Anal. E. G. Radley.
VI. B. component. Autobrecciated keratophyre. Grangegeeth (231). Anal. B. E. Manistre.
VII. "Lime bostonite." Abercastle, Pembroke. J. V. Elsden (1906), p. 596.

An analysis has also been made of the B component of an autobrecciated keratophyre (231). The principal features here are the high soda content and the low iron percentage. Keratophyres were also described by Thomas from Skomer island, but no analysis was made as they were considered by him to be very close to the "lime bostonites" of Elsden (1905). Elsden's analysis is also given in Table 1, and shows considerable similarity with the Grangegeeth keratophyre.

Calculations of the norms bear little relationship to the modes of these highly altered rocks, but the Niggli molecular norms of Table 2 give an indication of what might have crystallised from melts whose compositions were those of the analyses. Thus the presence of olivine in the norm for (206) and in smaller amount for (220) agrees with the observed occurrence of olivine pseudomorphs. It is thus reasonable to assume that, after the replacement of the original olivine by carbonate, the released femic material has remained essentially within the rock, appearing as chlorite or serpentine. Again, the composition of the normative plagioclase is considerably more anorthitic than that now present. If, therefore, the existing albite phenocrysts are the result of the albitisation of andesine or labradorite felspars, then the released lime and alumina has remained in the alteration products in the groundmass.

Table 2.

Molecular Norms calculated according to Niggli on the lines of the C.I.P.W. scheme.

Rock	Felspar			Diopside			Hyp.		Olivine					
	Or.	Ab.	An.	Wo.	En.	Fs.	En.	Fs.	Fo.	Fa.	Ct.	Ilm.	Mt.	Ap.
206	8·4	30·8	19·1	4·8	4·1	0·7	—	—	13·0	2·2	10·7	2·2	3·3	0·7
220	10·3	37·1	23·2	3·3	2·9	0·3	6·4	0·9	3·8	0·4	3·3	2·9	4·5	0·7

Molecular values used in calculating the Norms.

Rock	Kp.	Ne.	Cal.	Cs.	Fs.	Fa.	Fo.	Ct.	Ilm.	Cp.	q.
206	5·0	18·5	11·4	3·6	3·4	4·4	15·6	10·7	2·2	0·7	24·5
220	6·2	22·2	14·0	2·5	4·5	3·4	10·0	3·3	2·9	0·7	30·3

Molecular values (less CO_2) and Q-L-M values used in Fig. II.

Rock	Cp.	Ru.	Kp.	Ne.	Cal.	Cs.	Fs.	Fa.	Fo.	q.	Q	L	M
206	0·4	1·2	5·1	19·9	12·1	12·4	3·5	6·4	16·6	22·4	22	37	41
220	0·4	1·5	6·2	22·5	14·2	5·5	4·6	5·7	10·2	29·2	29	43	28
231	0·4	0·3	6·3	30·7	11·2	1·2	0·7	4·0	8·9	36·3	36	48	16

The principal alterations and replacements seen in the suite may be grouped as follows:—

anorthite+Na+Si→albite+Ca+Al

olivine→calcite+Mg+Fe+Si

hornblende→ankerite→calcite+Mg+Fe+Si

olivine→serpentine+Fe

hornblende→chlorite+Ca+(Al).

Chlorite, carbonates, and some epidote, in the groundmass may contain the elements released during these processes. The appearance of the felspar phenocrysts in the basaltic lavas suggests that they may have been affected by albitisation,

as pointed out in the Petrographic section, but the groundmass laths give no indication of being other than of primary crystallisation. The question whether the lavas acquired their sodic tendency by metasomatic additions from an external source or represent the products of a primary sodic magma, is therefore one of some difficulty.

One effect of introducing soda and silica into the rock without significant removal of anything else will be to increase the ratio of soda to potash present. A high value of this ratio has already been noted as a feature of spilite analyses, and is emphasised when it is plotted against silica, as has been done in Fig. 1 for the analyses given by Dewey and Flett (1911). This figure also shows the trend of the ratio in the Mull normal magma series, and in the Skomer series, taken from the variation diagrams for these areas. The two series have been chosen, as examples of a calc-alkaline sequence, and one in which sodic rocks of primary crystallisation have resulted, an assumption for which Thomas gives good reasons (1911, p. 209).

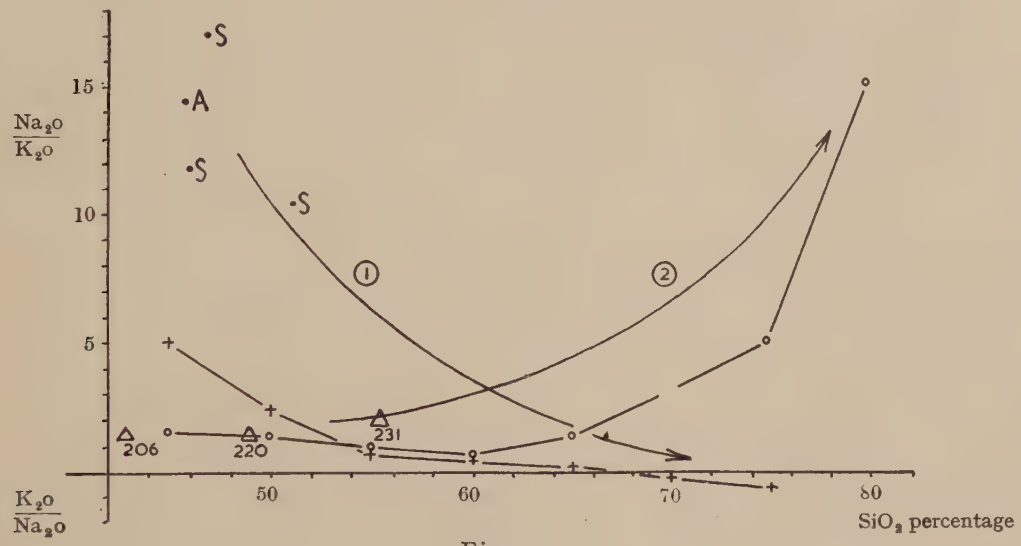

Fig. 1.

Diagram showing the trends of the soda/potash ratio for various rock series.

—+—+—=The Mull normal magma series.

—O—O— =The Skomer volcanic series. (Thomas, 1911).

S=Plots from the analyses of spilites given by Dewey and Flett (1911).

A=Plot of the average spilite given by Wells (1923).

△206=Plots of the analyses from the Grangegeeth volcanic series.

① =Suggested trend for a calc-alkaline series which has been metasomatically albitised.

② =Suggested trend for series in which the sodic nature of the magma is primary.

The amount of increase in the soda/potash ratio occasioned by the metasomatic replacement of anorthite by albite must vary with the anorthite content of the

original rock. It is therefore greatest in basic rocks and least in acid ones, where little albitisation is to be expected unless the replacement of potash felspar is also accomplished at the same time. This is a much more difficult achievement owing to the limited solid solution between albite and orthoclase, and judging from cases where it has been reported ample textural evidence is to be expected. It is therefore possible to envisage the trend which the soda potash ratio would follow in a calc-alkaline rock series in which all the anorthite has been replaced metasomatically by albite. Such a trend is indicated by the arrow labelled (1) in Fig. 1. The essence of this trend is that it converges on that of the normal calc-alkaline sequence, the starting point depending on the alkali ratio of the initial rock or magma.

The course of the ratio for a primary sodic magma is not subject to these requirements. As suggested by the Skomer island series the acid differentiates of such a magna are more likely to show an increase rather than a decrease in their sodic character. This sort of trend, typified by arrow (2) in Fig. 1 is opposed to that for a metasomatised series regardless of the point on the graph at which the series starts, and may be significant in distinguishing the primary or secondary nature of the albite where sufficient data is available.

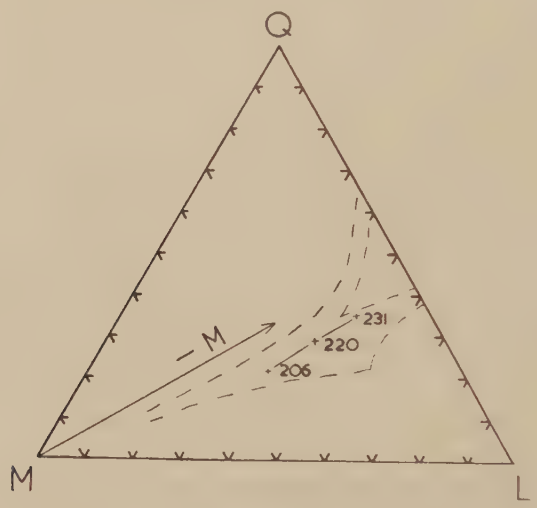

Fig. 2.

Q-L-M diagram after Niggli (1945) showing the relation of the Grangegeeth analyses to the field of the spilites and associated rocks.

There is the further possibility that the two effects may be superimposed. The tendency here will be to reduce the divergence between the trends, but the effect is limited by the fact that a magma initially rich in soda is unlikely to produce much anorthite to be albitised. As far as the data go the Grangegeeth series appears to fall into this category. The trend of the alkali ratio lies close to that of the Skomer series with a tendency to increase. This is in agreement with the supposition that the oligoclase laths of the groundmass are a primary crystallisation. If the textural

evidence that the phenocrysts have been partly albitised be accepted, then it may be considered as an effect superimposed on the general trend of differentiation.

Some further support for the Grangegeeth series as a differentiated sequence is forthcoming when the analyses are plotted on a Q-L-M triangular diagram, as advocated by Niggli (1950). This form of presentation was used by Burri and Niggli to summarise the chemical data of the spilite-keratophyre association (1945, p. 491). Fig. 2 is based on this diagram, the dotted lines enclosing the field of the spilites and related rocks described by Dewey and Flett (1911), Benson (1915), and Sundius (1930). In compiling the Q-L.M values the CO_2 percentage is first subtracted, and the analysis recalculated to 100. This procedure assumes that all the Ca in the carbonate is of primary origin, a supposition of some doubt especially in vesicular rocks. Equally suspect would be the subtraction of enough Ca to make Ca Co_3, for this would assume that all the Ca in the carbonate had been introduced. Some latitude is thus apparent in the position of the plots according to which assumption is favoured. The field outlined on the diagram is wide enough to include basalts of the mugearite type and many other basalts which would not be classified as spilites (see for example Niggli 1950, p. 113). The Grangegeeth rocks lie in an almost straight line whose direction is nearly parallel to that of minus M. As pointed out by Niggli (1950, p. 114), this involves a course of differentiation in which olivine, etc., is removed from the liquid. It is thought likely therefore that the Grangegeeth series represents the partial differentiation of a mugearitic magma on which the effect of partial albitisation has been superimposed.

IV.—Relationships with other Ordovician areas.

IV(a).—Ireland.

An inlier of lower Palæozoic rocks of similar age occurs at Kildare, south-west of Dublin, and was described by Gardiner and Reynolds (1896). The igneous rocks present are described as augite andesites (including two hornblende-bearing flows), porphyritic and amygdaloidal basalts, and a fossiliferous ash. The mineralogy of the basalts shows many similarities with the Grangegeeth rocks. Thus fresh black augites up to $\frac{1}{4}$-inch long are found in one basalt, haematite staining is recorded, and olivine pseudomorphs are suggested. In contrast, bastite pseudomorphs after rhombic pyroxene are described, while hornblende is only recorded from two localities. The volcanic rocks underlie the Kildare limestone, which is correlated with the Coniston limestone of the Lake District, and are therefore of closely similar age to the Grangegeeth series.

Comparable Ordovician volcanic areas include the Portraine inlier (Gardiner and Reynolds, 1897), and Balbriggan, Co. Dublin (Gardiner, 1899). The Portraine rocks are amygdaloidal basalts and augite andesites with porphytitic felspars and abundant iron oxides. In common with the Grangegeeth basalts one flow is described as having large porphyritic augites conspicuous in the hand specimen. At Balbriggan a series of augite andesites is determined to be of Bala age, the characteristic features being decomposed plagioclase phenocrysts set in a groundmass of chlorite, calcite, and felspar microlites.

To the south, in the counties of Waterford and Wexford, Ordovician rocks have been described by F. R. C. Reed (1900), while F. H. Hatch (1888 and 1889) has studied the petrological characters of the felsites occuring on sheets 138 and 139 of. the Irish Survey. Although sodic rocks are recognised as widespread they are much more acid than the Grangegeeth rocks, and many of them would probably be described as soda rhyolites. Basaltic rocks are not mentioned by either of these authors.

Finally, much farther north in the foothills of the Sperrin mountains, N.E Tyrone, Cole (1897) and Hartley (1933) have recorded lavas considered to range up to Caradocian in age. Among the andesite flows traced by Cole on Slieve Gallion are some hornblendic varieties with signs of brecciation (Cole, 1897, p. 222). Flow-brecciated trachytes are also mentioned by Hartley at Beaghbeg, near Kerag (1933, p. 228). The majority of the volcanic rocks described are however basalts and spilites with the frequent development of pillow structures.

IV(b).—Wales.

In contrasting the Kildare inlier with the British Ordovician volcanics it was pointed out by Watts, in the discussion on Gardiner and Reynold's paper (1896), that olivine and hornblende are decidedly rare in the Welsh province of this date. The most notable exception is the Skomer island succession (Thomas, 1911), whose close comparison with the Grangegeeth series has already been stressed in Section III.

In the Lleyn peninsula soda-rich volcanic rocks are described by Matley (1932) in the district round Sarn, and again in the Pwllheli, Llanbedrog, and Madryn area (1938). The Sarn rocks are spilites and rhyolites of Arenig to Llanvirn age and thus older than the Grangegeeth occurrence, but the Pwllehi, Llanbedrog and Madryn volcanics are considered by Matley to be chiefly or wholly of Caradocian age (1938, p. 557). The three principal varieties recorded are spilites, keratophyres and andesites. Of these, the spilites are so highly altered that the character of the felspars is not usually determinable. The keratophyres consist of micro-phenocrysts of albite-oligoclase in a base of albite or oligoclase microliths with magnetite, chlorite, and epidote. Autobrecciation is frequently observed. The andesites contain andesine-labradorite phenocrysts, while the ferromagnesian minerals include monoclinic and orthorhombic pyroxenes and chlorite pseudomorphs after hornblende.

IV(c).—England.

The stratigraphical and palæontological evidence correlating the Grangegeeth series with the Borrowdale Volcanic Series of the English Lake District is discussed by Harper in the preceding paper. The petrological comparison does not however appear to be a close one. The dominant types are andesites or rhyolites although some of the rocks described by J. F. N. Green are called keratophyres (1915). This name appears on some of the slides in the collection at Liverpool University, but is not used in the paper referred to above. Enstatite and augite are the typical ferromagnesian minerals in the andesites, and olivine has not been recorded even from the Eycott basalts. Analyses given by Mitchell (1930) confirm that the region as a whole is not one rich in soda, the only example being the " spilite " dyke from Buck Crag (1930, p. 3).

IV(d)—The Southern Uplands of Scotland.

Rocks of strictly comparable age occur in the Tweeddall group of lavas. Eckford, Ritchie, and Balsillie (1930), describe quartz keratophyres which contain an altered amphibole provisionally identified as riebeckite. They appear to be of finer grain and less brecciated than the Grangegeeth series, but their sodic character is well established.

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EXPLANATION OF PLATES.

PLATE 8.

Specimen from the autobrecciated keratophyre group, loc. (231), showing the components A, B, and C, referred to in the text.

PLATE 9.

FIG. 1. Mugearitic dolerite. Loc. (220). Analysed.

FIG. 2. Mugearitic basalt. Loc. (206). Analysed.

FIG. 3. Pseudomorphs of calcite after olivine. Loc. (5). (Loose block).

FIG. 4. Augite keratophyre. Loc. (234).

FIG. 5. Autobrecciated keratophyre, showing spherulitic felspar laths. Loc. (231). Crossed polars.

FIG. 6. Pseudomorphs of chlorite after hornblende in autobrecciated keratophyre, component A. Loc. (231).

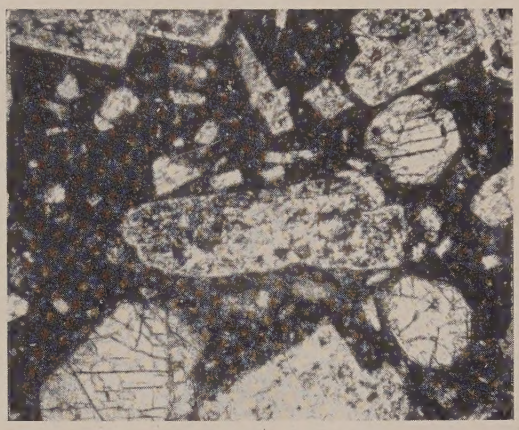
All photomicrographs approx. × 27 and by plane polarised light, except where otherwise stated.

A
B
C
CM & MM

FIG. 1

2

3



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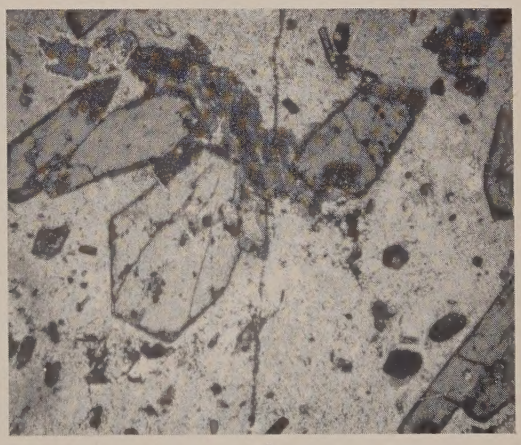
5



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